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# PATENT SPECIFICATION

DRAWINGS ATTACHED

*Inventor:* RONALD ERNEST ZOLLER

**893,251**

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COMPLETE SPECIFICATION

## Improvements in Automatic Control Systems for Vapour Generating Plant

We, BABCOCK & WILCOX LIMITED, a British Company, of Babcock House, 209/225 Euston Road, London, N.W.1 do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be described in and by the following statement:—

This invention relates to automatic control systems for vapour generating plant. In the use of a modern high-capacity vapour generator for supplying steam at high pressure to a turbine in a power station, the starting up of the vapour generator and turbine in a manner ensuring safety of the plant is a complicated process calling for skilled and experienced operators able to act quickly and with judgement upon the occurrence of abnormal conditions. The shutting down of the vapour generator likewise requires skill and experience and particularly under emergency conditions may demand immediate and correct action. If, during starting up or shutting down an operator fails to take correct action sufficiently quickly, or at all, or exerts a wrong control, the possibility arises that the plant may be rendered unavailable for a long period of time and the resultant damage may be very costly to repair.

The modern high-capacity vapour generator utilises as firing means a considerable number of burners which may, for example, be oil burners or pulverised fuel burners of which different burners or groups of burners are supplied with pulverised fuel from respective mills and commonly the combustion air is supplied by a plurality of forced-draught fans and a plurality of induced-draught fans. In the event of failure of a fan, operation of the vapour generator in some cases may be continued safely at reduced load but, inasmuch as the reduced combustion air supply may result in flame instability if all burners are retained in operation, the necessity arises of shutting down a burner or burners. This would be a simple requirement were it not for the fact that a burner or burners may be out of operation and must not be selected for shutting down. Consider, for example, the case of a pulverised fuel-fired generator having a number of pulverising mills of which at least one is a reserve mill, whilst the burner shutting down is to be effected by terminating operation of a mill or mills. Clearly a mill or mills other than a reserve or inoperative mill must be chosen for shutting down. Whilst in theory this difficulty may be overcome by the use of suitable interlocks, as the number of mills is increased the complication becomes so great that interlocking is hardly a practical solution.

During operation of a vapour generator fired with a fuel containing solid incombustible matter, the necessity arises of cleaning exterior heat exchange surfaces from time to time. The cleaning may be accomplished by a system of blowers or shot cleaning may be used in an upright pass containing convection heat exchange surfaces. Whilst in general the blowers are power operated and subject to automatic control to effect the actuation in proper sequence, the initiation of the cleaning operation calls for the attention and judgement of an operator. If on the one hand the operator effects cleaning of the surfaces too infrequently, the boiler efficiency suffers through a reduction in the effectiveness of the heat transfer surfaces. If on the other hand cleaning of the surfaces is carried out too often energy is uselessly dissipated in the cleaning medium and there is unnecessary wear on the cleaning apparatus.

The present invention includes a control system adapted to start up or shut down a vapour generator, wherein the system includes storing means adapted to contain a coded programme and automatically to put the programme into effect by the issuance in succes-

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sion of signals each expressed as a particular sequence of states, each state being a binary state, that is to say a state selected from two possible states.

The invention will now be described, by way of example, with reference to the accompanying diagrammatic drawings, in which:—

Figure 1 is a diagram indicating in sectional side elevation a steam generating and superheating and reheating unit, auxiliary equipment thereof, a two stage steam turbine, and a digital computer arranged to control the operation of that unit and its auxiliary equipment, the unit being shown in section taken on the I—I of Figure 2 and as viewed in the direction indicated by the arrows;

Figure 2 is a front elevation of the unit shown in Figure 1, as viewed in the direction indicated by the arrows II—II;

Figure 3 is a diagram indicating condition sensing devices and controlling devices associated with the unit and its auxiliary apparatus;

Figures 4 to 19 are diagrammatic representations of various types of sensing and controlling devices suitable for use in an arrangement such as that of Figure 3;

Figure 20 is a diagram showing a control system utilising sensing and controlling devices shown in Figure 3;

Figure 21 is a diagrammatic representation of a local controller shown in Figure 20; and

Figures 22A and 22I taken in sequence, set out as a flow diagram the sequence of events in a digital computer as it starts the unit of Figures 1 and 2 from a cold state.

Referring first to Figure 1 and Figure 2 of the drawings, the steam generating, superheating and reheating unit 1 includes two vertically elongated furnace chambers 2A and 2B arranged side by side and separated by a water tube partition wall X, the other walls of the furnace chambers being lined with steam generating water tubes arranged for a natural circulation of water and connected at their upper ends to a steam and water drum 3. A common gas pass 4 extends sidewardly from upper regions of both furnace chambers 2A and 2B and communicates with a downpass 5.

Thirty two pulverised fuel burners 6 disposed in four horizontal rows of eight burners each are so arranged that four burners in each row discharge through the front wall 7 of the furnace chamber 2A and the remainder discharge through the front wall of furnace chamber 2B. These burners are supplied through pipes 8 with a mixture of pulverised coal and entraining primary air, and are supplied with secondary air from compartments 9A, 9B of a surrounding air box 9 respectively associated with the two furnace chambers 2A, 2B. A radiant superheater 10 extends across the front wall of the two furnace chambers in the vicinity of the pass 4. In the common gas pass 4 are arranged a secondary superheater 11 and the final stage 12 of a reheater of which the initial stage 13 is disposed in the downpass 5. In the downpass 5, below the stage 13, are arranged a primary superheater 14 and, below that, an economiser 15. At the two opposite sides of the gas pass are provided Ljungström air heaters 16A and 16B respectively, each driven by its own electric motor, referred to as 17A, 17B of which 17B is shown in figure 3, having motor actuated controllers referred to as 17XA, 17XB, of which 17XB is shown in figure 3. The steam space of drum 3 is connected by a pipe 18 to an inlet header 19 of primary superheater 14, outlet header 20 of which is connected by a pipe 21 to inlet header 22 of the radiant superheater 10. Outlet header 23 of that superheater 10 is connected by a pipe 24 to inlet header 25 of the secondary superheater 11, the outlet header 26 of which is connected by a steam main 27 to the inlet of the high pressure stage 28 of a turbine 29. The outlet of stage 28 is connected by a steam main 30 to inlet header 31 of the reheater initial stage 13, the tubes of which continue into the reheater final stage 12, and outlet header 32 of which is connected by a steam main 33 to the inlet of low pressure stage 34 of the turbine 29.

Two forced draught fans 40A, 40B have their outlet ducts 41A, 41B respectively connected to air ducts 42A, 42B of the air heaters 16A, 16B, which ducts are respectively connected to compartments 9A, 9B of the windbox 9. Four coal pulverising mills are provided each feeding one horizontal row of eight fuel burners 6, and each of air heater ducts 42A and 42B supplies hot air to two mills. Thus air heater duct 42B is connected to the windbox 43 of an air swept coal pulverising mill 44 to which coal is fed from a storage hopper 45 through a gravity pipe 46 and a motor driven coal feeder 47. The mill 44 includes a classifier and fine particles of pulverised coal are swept by air from the windbox 43 from the mill through a duct 48 leading to the pipes 8 of the upper row of burners 6. The other three mills are not shown in the drawings but are similar to that described above and are arranged severally to feed pulverised fuel to the other three horizontal rows of burners 6.

The flue gas exit of air heater 16B is connected to a group of cyclone grit arrestors (not shown) the outlet ends of which are connected to the inlet of an induced draught fan 49B from which the outlet duct 50B is connected to a chimney, not shown, and the flue gas exit of air heater 16A is similarly connected through an induced draught fan 49A and outlet duct 50A, not shown, to the chimney.

For the purpose of control of the temperature of reheated steam, a by-pass 53 controlled by a motor actuated damper 54 extends from adjacent reheater section 12 to a level in downpass 5 below the reheater section 13.

The steam generating, superheating and re-

heating unit described above may be taken, for the purposes of the present specification, as being of orthodox construction, the various details of the unit being well known in the steam boiler art.

The unit described above includes a multiplicity of control devices in the form of valves, dampers and electric motors driving fans, air heaters and pumps, and a multiplicity of sensitive devices in the form of limit switches, pressure switches, temperature switches, thermocouples, flow meters, tacho-generators, switch-position indicating contacts, and moving-element position indicating devices. The locations of these control devices in these sensitive devices are indicated in Figure 3, in which the various parts of the unit shown in Figures 1 and 2, and of auxiliary equipment, are shown in non-spatial arrangement.

Since these control devices and these sensitive devices fall into certain natural groups according to the type of effect they produce, one device representative of each group will be described in detail below with reference to Figures 4 to 19 before proceeding to a detailed discussion of Figure 3 of a digital computer 58 shown in Figure 1.

Figure 4 illustrates a valve 61 connected to control fluid flow in pipe line 62 and having an actuating shaft 63 movable by a motorised control device 64 between a first position in which the valve is open and a second position in which the valve is closed. It is desired to provide positive remote indications when the valve is fully closed and when it is fully open. A double limit switch 65 is provided having a movable armature 66 which completes the circuit between one pair of contacts only when the valve is fully closed and completes another circuit between a second pair of contacts only when the valve is fully open. In the following description valves fitted with a double limit switch in this manner are allotted designations consisting of the letters V:LL: followed by a number, and in the drawings, to relieve congestion, these designations are applied to the output lead 67 from the limit switches.

Figure 5 illustrates a valve 71 connected to control fluid flow in a pipe line 72, and having an actuating shaft 73 movable by a motorised control device 74 between a first position in which the valve is open and a second position in which the valve is closed. It is desired to provide a positive remote indication when the valve is at a selected limiting position, and a single limit switch 75, similar to the limit switch 65 but with one pair of contacts either omitted or not used, is coupled to the actuating shaft 73. In the description valves fitted with single limit switches in this manner are allotted designations consisting of the letters V:L: followed by a number, applied to the output lead from 77 from the limit switch.

Figure 6 illustrates a valve 81 connected to control fluid flow in a pipe line 82 and having an actuating shaft 83 movable by a motorised control device 84 between a first position in which the valve is open and a second position in which the valve is closed. It is desired to provide a positive remote indication of the degree of opening of the valve and, since the indication is to be fed to a computer operating with binary scale numbers, to give the indication in the form of a binary number. In the arrangement shown, the degree of accuracy required in the remote indication is such that the travel of valve actuating shaft 83 may be considered as divided into 64 equal parts and all that is required is an indication of in which part the shaft 83 lies. A device 85, which will be referred to as a local digitaliser, is indicated in Figure 6 and is shown in diagrammatic form in Figures 7 and 8. It has a rotary input shaft 86 suitably coupled to the shaft 83, extending through a bearing 87 provided in the wall of a casing 88 and carrying, inside the casing a large spur gear wheel 89. Gear wheel 89 engages a much smaller gear wheel 90 mounted on a shaft 91 supported and positioned by a bearing 92 secured to the casing 88, the velocity ratio of the drive from shaft 83 to shaft 91 being chosen so that, as the valve moves from one limit of its travel to the opposite limit, the shaft 91 completes just less than one complete revolution. Shaft 91 also carries a disc 93 of insulating material upon one face 93A of which is formed a printed electrical circuit indicated diagrammatically only in Figure 8. This circuit is in the form of a metal film covering the whole face of disc 93 with the exception of a central area 95 and an arrangement of arcuate apertures indicated generally by 96. These arcuate apertures are in the form of parts of six concentric circles centred on the axis of shaft 91. At the inner circle there is one arcuate aperture 96A embracing 180 degrees; at the next circle there are two equally spaced arcuate apertures 96B each embracing 90 degrees; at the next circle there are four equally spaced arcuate apertures 96C each embracing 45 degrees; at the next circle there are eight equally spaced arcuate apertures 96D each embracing 22½ degrees; at the next cycle there are sixteen equally spaced apertures 96E each embracing 11¼ degrees; and at the outermost circle there are thirty-two equally spaced apertures 96F each embracing 5⅝ degrees. The manner in which the apertures in each circle are oriented with respect to those of the other circles is indicated in Figure 8, the important features being that the ends of every aperture lie on one of the sixty-four equally spaced radial lines which severally pass through the ends of the apertures and, at one of these radial lines indicated by the dotted line 102, the leading ends of apertures 96A, 96C, 96E and the trailing ends of the aper-

tures 96B, 96D and 96F are all in alignment. The arrow Y indicates the sense of rotation of the disc 93 taken in deciding which are leading and which are trailing ends of the apertures.

A lug 99 is provided on the casing 88 and carries a block of insulating material 100 formed with seven cylindrical holes 101 having their axes parallel and lying in a plane normal to the disc 93 and passing through the axis of shaft 91. The block 100 is close to the face 93A of the disc 93 and the seven holes 101 severally contain seven plungers 112 guided by the walls of the holes and biassed by springs 103 into contact with the disc face 93A. Each of the six radially outer plungers is so positioned as to engage the disc 93 at one of the circles of apertures 96 as the disc rotates and the end in contact with the disc is such that, when the plunger is opposite one of the apertures, the plunger enters the aperture to touch the insulating portion of the disc 93 without contacting the metal film of the electrical circuit. The seventh innermost plunger 112 contacts the metal film continuously. Electrical leads severally from the seven plungers 112 are bound together in an electrical cable denoted in Figure 6 by the output lead 107.

The lead connected to the radially innermost plunger 112 is a common lead, and through the plunger is at all times connected to the metal film on the face 93A of disc 93. When that common lead is energised, the state of energisation of each of the other six plungers 112 will depend upon whether or not it is in an aperture 96, and this again will depend upon the angular position of the disc 93. Over one complete rotation of the disc 93, there will be 64 unique combinations of states of energisation of these six plungers 112, so that the output from the device gives an indication of the position of the disc 93 and thus of the positions of the input shaft 86 and the valve actuating shaft 83. In the description below, valves fitted with a local digitaliser are given the designation V:D followed by a number and applied to the output lead 107.

Figure 9 illustrates a damper 121 arranged to control gas flow in a duct 122 and having an actuating shaft 123 movable by a motorised control unit 124 between a first position in which the damper is open to a desired extent and a second position in which the damper is closed. To provide a positive remote indication when the damper is in a limiting position, a limit switch 125 similar to the limit switch 65 of Figure 4 is coupled to the actuating shaft 123. In the description below dampers fitted with such a double limit switch are allotted designations consisting of the letters D:LL: followed by a number and in the drawings this designation is applied to the ouput lead 127 from the limit switch. Where only one limiting position of the damper is to be remotely indicated, a switch similar to the switch 75 of Figure 5 is used and the designation D:L: followed by a number is given.

Figure 10 illustrates a damper 131 arranged to control gas flow in a duct 132 and having an actuating shaft 133 movable by a motorised control unit 134 between a first position in which the damper is open to a desired extent and a second position in which the damper is closed. In order to provide a remote indication of the degree of opening of the damper 131, a local digitaliser 135, similar to the digitaliser 85 described above, has its rotary input shaft 136 connected to the actuating shaft 133 and provides its indication through an output lead 137. Dampers provided with a local digitaliser in this manner are given the designation D:D: followed by a number, applied to the output lead 137.

Figure 11 illustrates a movable element 141 which could be, for example, a furnace-starting-up oil burner, having an actuating shaft 143 movable by a motorised control unit 144 between a first position and a second position. In the case of the oil burner, these two positions could be respectively the forward position in which the oil burner is advanced into a furnace chamber during starting up of the furnace, and the withdrawn position in which the burner is outside the furnace chamber and so protected from the radiant heat therein. A limit switch 145 coupled to the shaft 143 indicates whether the movable element 141 is in either of its limiting positions as described above in connection with Figure 4. Such a movable element with a double limit switch is given the designation ME:LL: followed by a number, applied to its output lead 147. Where remote indication of one limiting position suffices, a single limit switch similar to that shown in Figure 5 is used and the designation applied to the output lead is ME:L: followed by a number.

Figure 12 indicates a movable element 151 similar to the movable element 141, having an actuating shaft 153 movable by a motorised control unit 154 and having a local digitaliser 155 coupled to the actuating shaft 153 to provide a remote indication of limiting and intermediate positions of the movable element, in the manner described in connection with Figure 6. Such a movable element is given the designation ME:D: followed by a number applied to the output lead 157.

In each of the Figures 4, 5, 6, 9, 10, 11 and 12 a motorised control unit has been shown, provided to reposition an actuating shaft of some piece of equipment such as a gas flow controlling damper. Such motorised control units are well known in the art of control equipments and no detailed description is given herein. It will be understood that when such units are provided they will be provided with suitable connections to a remote control unit and with suitable limit switches to pre-

vent overrunning. Furthermore, in the case of valves, dampers and other auxiliary equipment which, during starting-up of the steam generating, superheating and reheating unit, can be positioned by hand before the actual starting-up operation is commenced, these motorised control units may be omitted with considerable economy, and where no motorised control unit is shown on the actuating shaft of a valve, damper or other piece of equipment it may be taken that the actuating shaft is intended to be manually set to a desired position.

Figure 13 illustrates in a diagrammatic manner means for giving a remote indication that a preset pressure has been exceeded in a container of which one wall is indicated at 161. A pressure sensitive device indicated diagrammatically at 162 as a piston 163 slidable in a cylinder 164 one end of which is in communication through a hole 165 with the interior of the container has an output shaft 166 the axial position of which is an indication of the pressure in the container. This can be effected by the provision of spring means, not shown, acting on the shaft 166 and tending to counter the force exerted by the pressure within the container. A limit switch 167, suitably similar to the switch 75 of Figure 5, is operatively connected to the shaft 166 and indicates when the shaft has reached or passed beyond a predetermined axial position and thus whether the pressure in the container is above or below the present value. Such pressure indicating means are indicated in the following description by the designation P:L: followed by a number applied to the output lead 168 from the switch.

Figure 14 illustrates the device shown in Figure 13 but with the switch 167 replaced with a local electronic amplifier 177 the output lead 178 of which thus provides a remote indication of the pressure in the container. Such devices are given the designation P:A: followed by a number and applied to the output lead 178.

Figure 15 illustrates in a diagrammatic manner means for giving a remote indication that a preset temperature has been exceeded in a container of which one wall is indicated at 181. A temperature sensitive device 182, suitably one incorporating a bimetallic strip, has an output shaft 183 the axial position of which is an indication of the temperature being measured. The output shaft 183 is operatively connected to a limit switch 184 similar to the switch 75 of Figure 5. The state of the switch 184 indicates whether the temperature in the container is above or below a preset value. Such temperature indicating means are given the designation T:L: followed by a number and applied to the output lead 188 of the switch.

Figure 16 illustrates in a diagrammatic manner means for giving a remote indication of the temperature in the container of Figure 15. Since the temperature sensitive device 182 can produce in its output shaft 183 neither the force nor the range of movement required to drive a local digitaliser of the type shown in Figures 6 to 8, the device 182 is arranged to control an electronic amplifier 194 the output lead 198 of which thus carries a signal indicative of the temperature in the container. Such temperature sensitive devices provided with a local amplifier are given the designation T:A: followed by a number and applied to the output lead 198.

Figure 17 illustrates means for indicating the flow of fluid in a conduit 201 and includes a constriction in the conduit 201, formed by an orifice plate 202, pipes 203 communicating with the conduit respectively on opposite sides of plate 202 being connected to differential pressure device 204 including a diaphragm biassed in one direction by a spring and subject on its two sides respectively to the pressures in the pipes 203. An electrical signal indicative of the position of the diaphragm is fed to an amplifier 205 and the output lead 208 of the amplifier carries a signal indicative of the position of the diaphragm and thus the flow of fluid in the conduit 201. Such differential pressure devices provided with a local amplifier are given the designation DP:A: followed by a number and applied to the output lead 208.

Figure 18 illustrates means for indicating remotely the speed of rotation of a shaft. A fan 211 is driven through a shaft 212 by an electric motor 213. The shaft 212 is coupled by gearing to a rotary input shaft 215 of a small electrical generator 216, the output voltage of which depends upon the speed of rotation of shaft 215 and thus shaft 212. Such shaft speed indicating devices, which will be referred to as tacho-meter generators, are given the designations S:SP: followed by a number and applied to the output lead 218 from the tacho-generator.

Figure 19 illustrates the manner in which auxiliary contacts 221 are arranged so that they are closed by a block 222 fixed to the switch arm 223 of an electrical switch when that switch arm is moved to close a main electrical circuit between a pair of leads 224. The block 222 is insulated from the switch arm 223, and the auxiliary contacts have an output lead 228 the state of energisation of which indicates whether the main electrical circuit is open or closed. Such switches provided with auxiliary contacts are given the designations SW:L: followed by a number and applied to the output lead 228.

Referring now to Figure 3, and utilising the foregoing description of the various components to abbreviate the references to the components provided, a feedwater pump 301 driven by an electric motor 302 and having an inlet pipe 303 has its outlet pipe 304 connected to the inlet of economiser 15. In the

pipe 304 are provided a water flow measuring device DP:A:305, a water pressure measuring device P:A:306 and a motor operated water control valve means comprising an orthodox feed water control valve 307 with a small by-pass valve 308 which opens before, and closes after, the valve 307 to permit the precise regulation of small water flows. The ends of the economiser 15 are connected together by a local recirculation pipe 311 provided with a stop valve V:LL:312 having a double limit switch. The economiser outlet is connected to the lower headers of the water tubes, indicated by 313, which line the furnace chambers and form the furnace partition wall, and these headers are provided with blown down valve means, one such means being shown as a stop valve V:L:315 and a regulating valve V:L:316, each of which has a limit switch which shows when the valve is closed.

The upper ends of the wall tubes communicate with the boiler drum 3, to which are applied a number of indicating and control devices. A water level gauge 317 is provided with isolating cocks V:L:318 and V:L:319 provided with limit switches which indicate when they are open and a drain cock V:L:320 which is provided with a limit switch which shows when the valve is closed. At a low level in the drum is provided blow down means having a motor operated control valve V:L:321 and a manually operated stop valve V:L:322 each provided with a limit switch which shows when the valve is closed. Connected to the steam and water spaces of the drum 3 is a water level indicating device indicated by DP:A:325. At its highest level the drum is provided with manually operated valve controlled air vents of which one is indicated by V:L:325, each valve being provided with a limit switch which shows when the valve is closed. To the steam space in the drum is connected a steam pressure indicating device P:A:326. Spaced apart around the circumference and along the length of the drum 3 are thermo-couples adapted to provide a measure of the temperature of the metal of the drum wall, two of these being shown at T:A:328 and T:A:329 respectively.

The steam space of the drum is connected by pipe means 333 to the inlet of primary superheater 14, the pipe means being provided with motor actuated condensate drain valves such as the valve V:LL:334 provided with a double limit switch. The lower header of superheater 14 is provided with a motor actuated condensate drain valve V:LL:335 provided with a double limit switch. The outlet of primary superheater 14 is connected to the inlet of radiant superheater 10 and the lower header of that superheater is provided with a motor actuated condensate drain valve V:LL:336 provided with a double limit switch. The outlet of radiant superheater 10 is connected to a spray attemperator 340 supplied with spray water through a pipe 341 in which are connected a motor actuated flow control valve 342 and a water flow measuring device indicated by DP:A:343. The steam outlet from attemperator 340 is connected to the inlet of secondary superheater 11, the inlet header of which is provided with a motor actuated condensate drain valve V:LL:345 provided with a double limit switch. The outlet of secondary superheater 11 is connected by steam main 27 to the inlet of the high pressure turbine stage 28, and adjacent the superheater outlet a thermo-couple T:A:356 provides a measure of the steam temperature. Incorporated in the steam main 27 is a motor actuated main steam stop valve V:L:357 having a limit switch, and a motor actuated by-pass valve V:L:358 connected across the valve 357 and provided with a limit switch. The parts of the steam main 27 on opposite sides of the valve V:L:357 are provided with motor actuated condensate drain valves V:LL:360 and V:LL:361 respectively, each valve being provided with a double limit switch. Between the valves and the turbine is arranged a steam flow measuring device DP:A:362.

The steam turbine high pressure stage 28 is provided with a thermo-couple T:A:365 arranged to provide an indication of the temperature of the metal turbine casing adjacent the steam inlet. The steam main 30 connecting the outlet from the turbine stage 28 to the reheater stage 13 is provided with a motor actuated condensate drain valve V:LL:366 having a double limit switch. The highest point in the reheater is provided with a motor actuated air vent valve V:L:367 having a limit switch which shows when the valve is closed. At the outlet from the reheater is provided a thermo-couple T:A:369 which provides an indication of the temperature of the reheated steam. The steam main 33 connecting the outlet from the reheater with the turbine low pressure stage 34 is provided with a motor actuated condensate drain valve V:L:371 having a limit switch which shows when the valve is closed.

It will be understood by those skilled in the art that in a large steam generating and superheating unit such as that described herein the unit is considered as consisting of a left-hand side and a right-hand side, as viewed in the direction in which the fuel burners discharge into the furnace chamber, and items such as fans, air heaters and steam mains from superheaters and reheaters occur in duplicate, one item being associated with the left-hand side and the duplicate item being associated with the right-hand side. Where items are duplicated in this manner, the convention adopted above of referring to items on the right-hand side with the suffix A and those on the left-hand side with the suffix B

will be maintained.

Considering now the air and gas flow through the unit, the forced draught fan 40B is driven by an electric motor 381 to the driving shaft of which is coupled a tacho-meter generator S:SP:382 and in the outlet duct 41B from the fan is arranged a flow measuring device DP:A:383. Beyond the device DP:A:383 is a side branch 384 from the duct 41B, for the supply of cold air under pressure to the pulverising mill 44. Beyond this branch is arranged a motor actuated air flow control damper 385. The air heater 16B associated with this duct is driven by the electric motor 17B and the driving shaft of this motor is coupled to a tacho-meter generator S:SP:386. The rotary air heater must be supplied with lubricating oil under pressure, and an oil pump 387 supplying oil to the air heater through a pipe 388 is driven by an electric motor 389 to the driving shaft of which is coupled a tacho-meter generator S:SP:390. Motor 389 is provided with a motor operated controller 389X. Air duct 42B leading from the air heater is provided with a damper D:LL:391 known as a "boxing-up damper" and provided with a double limit switch which shows when the damper is fully open and when it is fully closed. Beyond damper D:LL:391 a branch 392 leads from duct 42B to a manifold 393 connected to the air inlet of one of the four pulverising mills associated with the unit. These mills are severally associated with the four horizontal rows of fuel burners 6, and in the following description the mills will be designated respectively as mills I, II, III and IV to denote the number of the row which each supplies, counting down from the uppermost row of burners.

Mill I, illustrated in Figure 3, has its windbox 43 connected to the manifold 393, to which manifold are coupled the cold air branch 384 and the hot air branch 392. In the hot air branch 392 is arranged a motor actuated damper 394. In cold air branch 384 is arranged a motor actuated damper 395. In the manifold 393 adjacent the windbox is arranged an air flow measuring device DP:A:396. Across a part of the air flow passage through the mill, in which lies a bed of fuel undergoing pulverisation, the air pressure drop is measured by a device DP:A:397. The mill is driven by an electric motor 398 to the output shaft of which is coupled a tacho-meter generator S:SP:399 and the speed of which is controlled by a motor actuated control unit 400. The mill 44 requires a supply of sealing air under pressure before it can be permitted to commence grinding, and this is supplied by a fan 405 driven by an electric motor 406 having a motor actuated controller 406X and to the output shaft of which is coupled a tacho-meter generator S:SP:407. The fan is connected to the appropriate points on the mill through a duct 408 provide dwith a motor actuated damper D:L:409 having a limit switch which shows when the damper is closed. The mill feeder 47 is driven by a motor 412 the output shaft of which is coupled to a tacho-meter generator S:SP:413. The speed of the motor 412 is controlled by a motor actuated controller 414. In the outlet duct 48 from the mill is disposed a motor actuated gas flow damper D:LL:415 having a double limit switch which indicates when the damper is fully open and when it is fully closed. Also in this duct 48 is a temperature indicating device T.A.416.

Each of the thirty two pulverised fuel burners 6 has associated with it ignition means comprising an oil burner and an electrical ignition device for the oil burner, and further a flame sensitive device for indicating whether the oil burner is alight. As indicated in the inset A in Figure 3, for one of these oil burners oil is supplied through an oil line 420 to which are fitted a pressure indicating device P:L:421 having a limit switch which closes upon a predetermined pressure having been reached, and a temperature indicating device T:L:422 having a limit switch which closes upon a predetermined temperature having been reached by the oil. The oil burner 6 is movable by a motor actuated shaft from an advanced operative position to a retracted idle position, and means ME:L:423 indicate when the burner is fully advanced. The device which indicates whether the burner is alight is indicated by T:S:424. For ease of reference in the following description the general references T:S:424A, T:S:424B, T:S:424C, and T:S:424D are applied to the flame sensitive devices associated severally to the upper and the three other rows of burners. A motor operated valve 425 controls oil flow to the burner. Each pulverised fuel burner is provided with a secondary air register in the form of a number of curved vanes as indicated in Figure 12, and with an impeller which can be moved axially of the burner towards and away from the furnace chamber in accordance with the state and rate of firing by that burner. It has been found practical to utilise a single motor actuated operating shaft to operate, for each burner, both the air dampers and the axial repositioning of the impeller. For ease of reference, these actuating means, each of which is provided with a local digitaliser, are denoted by references ME:D:426A, ME:D:426B, ME:D:426C and ME:D:426D which refer respectively to those associated with the first, second, third and fourth rows counting down from the top.

Each of the furnace chambers 2A and 2B is provided with a flame responsive device mounted on its rear wall and adapted to indicate when combustion is lost completely in that furnace chamber. In Figure 3 is indicated such a device T:L:428B associated with the

furnace chamber 2B, and a similar device T:L:428A associated with the furnace chamber 2A will be referred to hereunder. Near to top of each furnace chamber is provided a temperature sensitive probe, that associated with furnace 2B being designated T:A:430B and that associated with furnace 2A being designated T:A:430A. Each probe is mounted on its own motor actuated shaft by which it may be inserted into and withdrawn from the stream of hot furnace gases, and this shaft has associated with it a limit switch which indicates when the probe is fully inserted and when it is fully retracted. The probe actuating mechanisms associated respectively with furnaces 2A and 2B are given the designations ME:LL:432A and ME:LL:432B. A pressure sensitive device P:A:434B is arranged to provide an indication of the gas pressure in furnace 2B, and a similar device PA:434A is associated with furnace 2A.

The induced draught fan 49B is driven by an electric motor 436B having a motor actuated controller 436XB to the driving shaft of which is coupled a tacho-meter generator S:SP:437B. In the gas duct 438B leading to this fan are disposed a motor actuated damper 439B and a motor actuated damper D:LL:440B, called a boxing-up damper, provided with a double limit switch, which provides an indication when the damper is fully open and when it is fully closed.

The induced draught fan 49A is similarly provided with a tacho-meter generator S:SP:437A, a motor actuated damper 439A and a boxing-up damper D:LL:440A.

The electronic computer 58 (see Figure 1) includes a memory store 500 having a number of locations in each of which is stored, or can be stored, a binary number consisting of one sign digit and five number digits. It also includes a programme store 501 which is similar to the memory store but in which each location is adapted to store a binary number consisting of 23 digits. Associated with this programme store is an automatic print-out device 503 which will, upon instruction by the actual computer section 502, print out the contents of some selected store in the computer. The actual computer section 502 has six stores called accumulators of which five are numbered off from 1 to 5 and can contain any number posted to them while the sixth is called a null accumulator and always contains zero, and is used for comparison purposes. Associated with section 502 is a control panel 504 by means of which the programme set up in the programme store 501 may be started and stopped, and the contents of the various memory stores printed out and changed if desired. The computer includes a clock and means for reading the time indicated by the clock.

Each instruction in the programme store is thus in the form of 23 binary digits split up into groups as follows:—

N—a seven digit binary number indicated a particular location in the memory store, or programme store, or in some cases merely a number;

X—a three digit binary number indicative of one of the six accumulators;

F—a six digit binary number of which the first three digits indicate a first and the last three digits a second octal number, that is to say a number selected from the group 0 to 7. The two term octal number thus set out defines some definite operation which the computer section 502 is to carry out;

M—a seven digit binary number, the computer effecting addition of the binary number M to the contents of selected location indicated by N before the operation indicated by F is carried out.

The computer during the control of the steam generating and superheating unit is required repeatedly to check whether some particular condition is fulfilled, if so to take one course of action, which may be merely to go on to the next step in the set programme, and if not to take another course of action. Thus the most commonly used functions F are of the following form:—

(a) Jump to N1 if X equals 0;
(b) Jump to N2 if X does not equal 0;
(c) Jump to N3 if X is greater than 0;
(d) Jump to N4 if X is less than 0.

The functions (a) to (d) are alternatives but may be combined as (a)+(b), or (a), (c) and (d).

Associated with the computer, and suitably mounted adjacent to it or even in the same enclosure, is a control unit 510 into which are brought input leads, indicated diagrammatically at 511, bringing information to the computer from different parts of the boiler unit, and from which extend output leads, indicated diagrammatically at 512, leading to motors actuating control devices associated with dampers, valves and other parts of the unit. Thus control unit 510 includes a selector switch actuated by suitable instructions from the computer section 502 and adapted, at the command of that section to feed any desired input 511 into the computer or activate any of the control devices through output leads 512.

The control unit 510 receives input signals of varying forms from the various devices described in connection with Figures 4 to 19. Thus, the input signals will be variously of single bit binary digital form for single limit switches L, of two bit binary digital form for the double limit switches LL, of proportional analogue form from the local amplifiers and tacho-meter generators, and of binary digital form from the local digitalisers D. The control unit is suitably adapted to digitalise those input signals not already in binary digital form so that they may be handled by the computer section. It will be appreciated that the

output signals to the various motorised control units will be such as to cause a control unit to drive in a forward or reverse direction or to stop, and such signals will be sent to the control units at the instruction of the coded programme in the event of some condition governed by the control unit requiring regulation. It will be further understood that the condition being regulated will be monitored by the computer under the instruction of the coded programme and at such time as the condition reaches its desired value the output signal to the associated control unit will be shut off causing the control unit to stop.

By way of example, at a stage in the starting up of the unit it may be necessary to check whether a certain valve is closed, if it is, to go on to the next stop in the programme, if it is not, first to shut the valve and then to proceed with the programme.

The instructions in the programme store would be of the form:—

INSTRUCTION 1.

N1—the number of the limit switch associated with the closed position of the valve;

F1—an instruction to select the input having the number N1.

INSTRUCTION 2.

N2—a negative number equal numerically to the input number N1 when the valve is closed;

X2—a selected accumulator;

F2—an instruction to store the indication of the selected limit switch in the selected accumulator X2 after adding N2.

INSTRUCTION 3.

N3—code number of programme instruction 6 below;

F3—jump to programme instruction N3 if contents of X2 equal zero.

INSTRUCTION 4.

N4—code number of instruction to cause activation of the motor which closes the said valve;

F4—an instruction to carry out the instruction N4.

INSTRUCTION 5.

N5—code number of programme instruction 1 above;

F5—jump to programme instruction N5 (i.e. 1 above).

INSTRUCTION 6.

This is the next stage in the programme.

It will be seen that the computer has checked whether the valve is closed; if the valve is closed then the next stage in the programme is adopted, instructions 4 and 5 being by-passed; if the valve is open action is taken to close the valve and the condition of the valve monitored until it is closed, whereupon the next stage in the programme is adopted.

The computer is adapted to print out by means of the automatic print out device 503 every instruction sent to activate control motors operating valves and dampers, together with time of origin for all such instructions. To this end, the coded programme includes with each instruction to operate a control motor an instruction to print out. Furthermore, when any instruction to a control motor is not followed by an appropriate change in the state of the limit switches or the like within a predetermined time, written into a coded programme instruction for the computer to monitor the said state, such failure to obey is printed out in red, by virtue of suitable instruction from the coded programme to the automatic print out device 503.

The apparatus shown in Figure 3 and described above can be arranged for detailed control entirely by the digital computer, in which case the leads from the various limit switches, digitalisers, amplifiers and motor actuators are all taken to the control unit 510. With such an arrangement, the cost of the various electrical cables leading from remote parts of the boiler unit to the computer becomes high. Furthermore, it is not easy to ensure that, should any component in the computer fail, the whole boiler unit will continue to operate in a safe manner. Alternatively the apparatus can be arranged for overall control by the digital computer while local controllers including analogue computer facilities perform some of the control operations.

It will be understood that certain variables to be controlled will vary according to some function of a limited number of other variables the values of which may be continuously metered and conveniently fed to a local analogue computer adapted to give an output signal in analogue form of that function. Such an output signal may be supplied, as is known in the art, to a local control unit adapted to compare the output signal with a desired or set value and to provide a control signal, suitably a three term signal comprising proportional, integral and derivative terms of the function, for supply to a control element adapted to regulate the variable to be controlled. In some cases where the regulation of the variable to be controlled is directly proportional to another variable the analogue computer may be dispensed with.

Such local control units and analogue computers may conveniently be incorporated in the boiler control system described and a suitable arrangement is described below in connection with Figures 20 and 21. The desired or set values of each control unit are suitably arranged to be controlled manually or by the digital computer and suitable manual-automatic switch means are provided. The controlled variable is monitored by the digital computer so that in the event of said con-

trolled variable being outside predetermined limits specified in the coded programme, then a warning may be given or shut down action taken according to the coded programme.

Figure 20 illustrates the alternative arrangement by local controllers mentioned in the last paragraph. Instead of the outputs from certain of the sensing devices shown in Figure 3 going direct to the computer 58 they are taken either directly to local controllers or in selected groups first to local analogue computers of simple design and then the outputs from these computers taken to local controllers. It has been found convenient in a few cases to take the output from a sensing device not only to a local controller or analogue computer, but also directly to the digital computer, since the value of the variable concerned gives information as to the state of readiness of some part of the equipment.

Referring in detail to Figure 20, output P:A:434A (gas pressure in furnace 2A) is fed to a local controller LC:1 which controls the motor actuated induced draught damper 439A. Output P:A:434B (gas pressure in furnace 2B) is fed to a local controller LC:2 which controls the motor actuated induced draught damper 439B. Output T:A:369B and output T:A:369A (temperatures of steam from left-hand and right-hand sides respectively of reheater stage 12) are fed to an analogue computer AC:1 which determines the mean value and feeds an appropriate signal to a local controller LC:3 which controls the motor actuated reheater by-pass damper 54. Outputs DP:A:383A and DP:A:383B (rates of air flow to right-hand and left-hand sides respectively) and output DP:A:362 (rate of steam flow) are fed to an analogue computer AC:2 which provides a measure of ratio steam flow: air flow as an output R:1. Outputs R:1, DP:A:343 (water flow to attemperator), T:A:356A and T:A:356B (temperatures of steam from right-hand and left-hand sides respectively of superheater 11), are fed to an analogue computer AC:3 which feeds an appropriate signal to a local controller LC:4 which controls the motor actuated valve 342 controlling the supply of water to the attemperator 340. Outputs DP:A:383B (rate of air flow to left-hand side of unit), DP:A:362 (rate of steam flow) and P:A:326 (steam pressure in drum), are fed to an analogue computer AC:4 which feeds an appropriate signal to a local controller LC:5 which controls the motor actuated forced draught damper 385B for the left hand side of the unit. Outputs DP:A:383A (rate of air flow to right-hand side of unit), DP:A:362 (rate of steam flow) and P:A:326 (Steam pressure in drum), are fed to an analogue computer AC5 which feeds an appropriate signal to a local controller LC:6 which controls the motor actuated forced draught damper 385A for the right-hand side of the unit. Outputs DP:A:362 (rate of steam flow), DP:A:305 (rate of feed water flow), and DP:A:325 (water level in drum), are fed to an analogue computer AC:6 which is suitably adapted to compute a function of the form $K_1h + K_2$ (s—f) where $K_1 + K_2$ are adjustable constants; h = drum level; s = steam flow; f = feed flow; and feed an appropriate signal to a local controller LC:7 which controls the motor actuated feed water control valves 307 and 308. Output P:A:326 (steam pressure in drum) is fed directly to a local controller LC:8 which controls the motor actuated damper D:LL:415 disposed in the duct 48 leading from the mill 44, and thus controls the rate of supply of pulverised coal from this mill to the furnace chambers. Output T:A:416 (gas temperature at outlet from mill 44) is fed directly to a local controller LC:9 which controls the motor actuated damper 395 disposed in the duct or branch 384 which leads cold air to the mill manifold 393. Outputs DP:A:396 (rate of air flow to the mill) and DP:A:397 (pressure drop across a part of the mill including a bed of fuel undergoing pulverisation) are fed to an analogue computer AC:7 which feeds an appropriate signal to a local controller LC:10 which controls the motor actuated controller 414 of the motor 412 driving the mill feeder 47.

The analogue computers AC:1 and AC:7 mentioned above can be of any suitable known type, for example, of a type adapted to compute an output or outputs from variable inputs according to a computer equation of the general form

$$(ax \mp by)\, cz \mp s \div (pu \pm qv)\, rw = 0$$

where x, y and z are variable inputs, u, v and w are variable outputs and a, b, c, p, q, r and s are adjustable constants. The analogue computers are respectively adapted to compute suitable functions of the signals fed to them dependent upon the observed or predicted operational characteristics of the roller unit. The local controllers LC:1 to LC:10 follow the general known design for such controllers but need to incorporate an additional facility whereby they are adapted for supervision and control by the digital computer.

Referring to Figure 21 the local controller LC:8 controlling the rate of supply of fuel to the unit from mill I, is shown in diagrammatic form; its input and output and its internal mechanisms may be electrical, pneumatic or hydraulic in character, but Figure 21 indicates the manner in which the different parts are combined. In the controller casing 520 is arranged a measured value section 521 fed with the input signal through a lead 522 and having a meter 523 upon which the value of the variable measured, in this case steam pressure, is indicated. A lead 524 transmits the input signal to the control unit 510 of the computer, so that the computer has available

to it at all times a measure of the steam pressure. Also in the casing 520 is a set value section 525 by which a desired or set value for the variable involved may be selected. Variations of the set value are effected by a reversible motor 526 connected by a lead 527 to the computer control unit 510, the set value being indicated by a meter 528 and a lead 529 transmitting a signal to the control unit 510 indicative of the set value, so that at all times the digital computer has available to it the set value and the ability to vary that value as it sees fit. Both the measured value and the set value are transmitted to an error section 530 of the controller by leads 531 and 532 respectively. The error section transmits continuously through a lead 533 a signal representative of the error to a control section 534. The actual form of section 534 will vary from local controller to local controller, but in general it will accept an input error signal and provide an output control signal which includes proportional and/or integral and/or differential terms derived from the error signal. This output control signal is fed to a manual/automatic selector section 535 through a lead 536. A manual control section 537 having a hand operated control knob 538 provides a variable control signal of the same form (e.g. electrical current) as that in lead 536, and this control signal is fed to section 535 through a lead 539. The manual/automatic selector section 535 is controlled by a reversible motor 540 connected by a lead 541 to the control unit 510 of the digital computer. The selected signal, chosen from that in lead 536 and that in lead 539, is passed on by section 535 through a lead 542 to an output section 543 which controls the activation of a motor unit 544 of the motor actuated damper D:LL:415. The output section 543 includes a meter 545 which indicates the value of the output signal fed to motor unit 544, and so facilitates manual control by the knob 538. A switch device SW:L:546 provides the control unit 510 with an indication of the setting of the manual/automatic selector section 535.

It will be appreciated that the local controllers LC:8, LC:9 and LC:10 and analogue computer AC:7 are repeated for each of the four mills provided.

It will be appreciated that should some fault develop in the digital computer occasioning the computer to relinquish control of the boiler unit the local controllers will control the boiler according to the set points existing at the local controllers at that time and will tend to maintain stable conditions in the boiler. By virtue of manual control of the set points the condition of the boiler can be varied in known manner so that satisfactory operation of the boiler may be maintained until the digital computer is able to resume control.

The computer is suitably adapted automatically to relinquish control should any fault arise therein and to this end the coded programme is arranged to feed a problem into the computer section at regular intervals and compare the computed solution with a correct solution on the programme. In the event of the comparison showing a discrepency the computer is prevented from exerting any further control action by virtue of relay means controlling the computer output and adapted to allow transmission of outputs from the computer only when there is no discrepency.

The operation of the various parts of the steam generating, superheating and reheating unit, and of the control equipment associated therewith and described above, will become clear from the following account of the starting up of the unit from a cold state.

The starting up of the unit is under the general control of the digital computer in accordance with a programme stored in its programme store 501 and Figures 22A to 22I set out in the form of a flow diagram the steps in the programme. The programme is initiated by the pushing of a start button on control panel 504, and the computer then reads and acts upon the first instruction in the programme store. Each instruction is complete in the sense that the next instruction is not initiated until that first instruction is deal with. The flow diagrams set out the sequence of events at the actual computer section, certain steps of the programme being omitted, or repeated, or delayed, in accordance with facts ascertained by the computer section. Thus the first item in the programme is a check of the fuel oil pressure. If that pressure is correct, the next step in the programme will be taken, but if not a sub-routine is adopted which involves first printing out that the pressure is too low, and then proceeding to the second step in the programme.

For the most part the flow diagrams are full and self explanatory. Certain points are amplified below. The references to L/H and R/H are respectively to the components associated with the left-hand and right-hand sides of the unit. In many cases a complete sub-routine is indicated by the words "Print out. Open valve. Check open", or the like, and the development of such a sub-routine will be clear to those skilled in the art. Often the flow lines indicated that such a sub-routine is followed by the resumption of the main programme, and of course in some cases the valve or damper concerned may not adopt the required position. This is quite in order when the resulting conditions in the unit are not dangerous, but in certain cases where danger would arise the sub-routine includes the instruction "stop programme" followed by a note "programme manually restarted". This indicates that the operator of the digital computer must take the initiative in continuing the programme, and in practice he will take steps to remove the obstruction to the pro-

gramme before he manually restarts the programme. At other points in the programme, such as for example the ignition of the oil burners, one may have to repeat the ignition procedure two or three times. To stop such a step being repeated interminably, one can either rely upon the operator to take the corrective action, or introduce a counter circuit which counts the number of times which the step is repeated, and upon a preselected number being reached, either passing on to the next step in the programme or stopping the programme as considered expedient when the programme is first laid down. It is, of course, important that each oil fuel burner is ignited before the associated pulverised fuel burner commences discharging pulverised coal.

The programme sets out to take the steam generating unit from the cold state to the state in which it accepts its full rated load. In central station practice, the turbine is linked to an alternator which is coupled to the national electrical grid system, and in such a case it is sufficient to decide a block load which the alternator, and thus the steam generating unit, is to carry. However, in the control system described above the steam generating unit is controlled to maintain a set steam pressure. The modifications necessary to carry a block load, in which steam flows rather than steam pressure is the main control, will be clear to those skilled in the art.

No close down procedure has been described in detail, but it may be developed by following the procedures normally adopted in closing down such units and making use of the various sensitive devices and control devices described above.

In a practical installation, the programme store will therefore include a plurality of coded programmes, one for starting up the unit from a cold condition and including modifying stages for starting up the unit when it is already in a hot condition, one for a normal shut down of the unit when the associated alternator is first taken off load and the turbine closed down, and a further programme for an emergency shut down of the unit upon dangerous conditions arising in the unit, the turbine or the alternator. The starting up programmes will normally merge into a normal running programme.

In order to preclude closing down of the unit upon the occurrence of conditions which, although undesirable, are not sufficiently dangerous to necessitate the closing down of the unit, the memory store can include permit signals. The computer is then arranged in response to suitable instruction in the coded programme, if unusual conditions arise, to inspect the permits stored in teh memory store and see whether the conditions arising correspond to one of the stored permits; if so, then the computer is instructed to print out the unusual conditions without closing down the unit, and at the same time to give audible warning to the operator that some action is required by him.

For example, the computer may monitor a temperature and find that it is above a desired value, it will then be instructed by means of a suitable instruction in the coded programme to inspect the relevant memory store and see if the monitored temperature is less than a maximum permitted value below which the vapour generator can continue to operate safely. If the monitored temperature is less than the permitted value then the computer is arranged to instruct the print out device to print out the monitored temperature and also to operate an audible or visual warning system to attract the attention of the operator to the unusual condition.

Whenever the computer prints out any item, it will automatically read the clock and print out the time, so that a permanent record is made of when untoward circumstances arise.

It will be seen that during starting up of the unit the furnace gas exit temperature measuring probes T : A : 430A and T:A:430B provide information that enables the firing rate to be limited so that the superheater tubes are not overheated. Furthermore, by comparison of the metal temperatures at different parts of the separator drums, T:A:328 and T:A:329 and similar points not indicated spaced along the length of the drum, the firing rate during starting up can be limited to prevent too great a temperature differential being developed between different parts of the drum wall. Strain gauges can be utilised instead of temperature measuring devices to indicate excessive local stresses.

The digital computer 58 can perform a large number of checks and calculations during the operation of the steam generating and superheating unit, and can control the unit and auxiliary equipment to give high operating efficiencies for the unit and the turbine.

One way in which the efficiency of the unit may be improved and maintained is to arrange the digital computer to initiate operation of apparatus for effecting cleaning of the external heat exchange surfaces of the unit. In an orthodox steam generating and superheating unit, fluid heater cleaners are arranged to discharge cleaning fluid over these external surfaces as and when necessary, and normally some predetermined frequency of cleaning is adopted, for example at the beginning or end of each eight-hour operating shift. This selected frequency is based upon past experience, but inevitably the cleaners will sometimes be operated when there is no real need and at other times will not be operated until some time after cleaning could with advantage be carried out. When the digital computer is to control the initiation of such cleaning, variable-responsive means arranged to be influenced by a variable or variables the value or values of

which depends upon the state of the external surfaces to be cleaned are adapted, when the value of a variable is such as to indicate the need for cleaning, to effect operation of the cleaning apparatus. Suitably, the cleaning apparatus is of a known form of automatically controlled apparatus adapted on initiation of operation by operation of a start device to carry out a full cleaning operation before switching itself off. The state of cleanliness of the vapour generating tubes which line the walls of the furnace chambers is obtainable, comparison of the load on the unit, utilising the measures of the rate of steam flow given by DP:A:362, and the furnace gas exit temperature, given by T:A:430A and T:A:430B. The computer can be programmed to compare these items, say every hour, and when their ratio falls below a predetermined value recorded on the coded programme or in an accumulator of the digital computer to effect operation of the start device and initiate cleaning of the external surfaces of the furnace wall tubes. In a similar manner the state of the external surfaces of the economiser can be deduced from a comparison of the pressure drop of the flue gases across the economiser and a measure of the rate of gas flow. To determine whether the superheater tubes require external cleaning, the computer can compare draught loss across the convection superheater with the rate of steam or gas flow, and in the case of the radiant superheater a measure of the increase in the temperature of steam between inlet and outlet headers with a measure of the rate of steam flow. It will be appreciated that the cleaning apparatus associated with the vapour generating tubes, the economiser surfaces and the superheater tubes suitably have individual automatic control systems with respective start devices adapted to respond to respective signals from the digital computer to initiate cleaning of the respective parts of the boiler unit according to their respective states of cleanliness.

Variations of the programme set out above for starting up from cold will be needed or will be desirable when the steam generating and superheating unit has a form different from that shown in Figures 1 and 2. Thus, for example, when there is but one furnace chamber but there are still left-handed and right-handed induced and forced draught fans, should one of the fans fail to start or cease to operate the computer can be arranged to distinguish the operative burners from the inoperative burners, if any, and to effect a reduction in the number of operative burners to a value suited to the number of fans in operation. This would suitably be followed by action by the computer to distinguish operative mills from inoperative mills and the reduction of the number of operative mills to a value suited to the number of fans in operation.

The digital computer 58 can be arranged by the provision of suitable instructions in the coded programme to control the starting up of the steam turbine. This requires first a check as to the temperatures of the various parts of the turbine casing, to ascertain by comparison of temperatures with permits stored in the computer whether a rapid or slow rate of heating up is desirable, and by virtue of suitable instructions in the coded programme to open the steam controlling valves at a controlled rate to give the desired rate of heating. Repeated checks are suitably made upon temperatures at different parts of the casing in order that large temperature differentials may be avoided by varying the rate of heating up the turbine. When the turbine is running at or at about its rated speed, its local automatic controller or governor is suitably arranged to take over control of the steam supply. During starting up and normal running the digital computer suitably monitors lubricating oil pressure, control system oil pressures, bearing temperatures, and turbine shaft eccentricity, so that should an unusual condition occur the computer can instigate the necessary action according to a suitable instruction in the coded programme.

It will be seen that in the above description the control system for the vapour generating and superheating unit includes storing means, the programme store, adapted to contain a coded programme and to put the programme into effect by the issuance in succession of signals each expressed as a particular sequence of states, each state being a binary state, that is to say a state selected from two possible states.

The strong means will usually form part of a binary digital computer, but may form part of a digital computer having a decimal system input and/or output.

WHAT WE CLAIM IS:—

1. A control system adapted to start up or shut down a vapour generator, wherein the system includes storing means adapted to contain a coded programme and automatically to put the programme into effect by the issuance in succession of signals each expressed as a particular sequence of states, each state being a binary state, that is to say a state selected from two possible states.

2. A control system as claimed in Claim 1, wherein the storing means contains a plurality of coded programmes, one for starting up the vapour generator from a cold state, at least one for starting it up from a hot state, one for a normal shut down and one for an emergency shut down.

3. A control system as claimed in Claim 2, wherein the storing means also contains a programme appertaining to normal running operation of the vapour generator.

4. A control system as claimed in Claim 2, wherein provision is made for effecting programme modification by permit means arran-

ged to store permit signals and adapted by the issuance of signals to permit a programme to proceed notwithstanding that states or conditions of respective elements of or associated with the vapour generator are unsatisfactory or the elements are withdrawn from operation.

5. A control system as claimed in any preceding Claim, wherein a programme includes testing signals and sensing means are arranged to effect signals indicative of states or conditions of the vapour generator or of elements of or associated therewith and comparison means are adapted to compare the testing signals and the comparison signals and in the event of the state or conditions being unsatisfactory to effect stopping of the programme or to effect rectification of the state or condition by a regulating action or by a departure from the normal sequence of the programme as may be appropriate.

6. A control system as claimed in any preceding Claim, wherein provision is made for checking the state of elements such as gauges or drains.

7. A control system as claimed in any preceding Claim, wherein means are adapted when a transmitted programme order is not obeyed to give an indication of the particular failure and stop the programme if continuance of the programme might lead to a dangerous condition, but if the programme may safely be continued merely to give an indication of the failure.

8. A control system as claimed in any preceding Claim, wherein automatic printing means are arranged to show in print at least those matters in relation to elements of or associated with the vapour generator which are found during the carrying out of a programme to require consideration or attention.

9. A control system as claimed in Claim 7 or Claim 8, wherein the system is arranged to control automatic printing means adapted to print out the orders transmitted in accordance with a programme, the time when an order is given or obeyed and in a distinctive manner any failure to obey an order.

10. A control system as claimed in any preceding Claim, wherein a starting up programme provides for the lighting of burners or groups of burners in sequence and upon failure of one burner or group of burners in the sequence to light up a control is exerted to light the next burner or group of burners if any in the sequence.

11. A control system as claimed in Claim 10, wherein the starting up programme provides for the lighting of lighting-up burners in sequence and the subsequent lighting of pulverised fuel burners or groups of pulverised fuel burners in sequence and selection of a pulverised fuel burner or group of pulverised fuel burners for lighting-up is made only if the corresponding lighting up burner is in operation.

12. A control system as claimed in any preceding Claim, wherein during starting up or shutting down means responsive to separator drum metal temperature at different locations on the drum walls are adapted to control firing rate in order suitably to limit temperature differences in and consequent stressing of the drum wall metal.

13. A control system as claimed in any preceding Claim, wherein the system is also arranged to control starting up of a turbine connected to receive vapour from the generator.

14. A control system as claimed in any preceding Claim, wherein means responsive to a particular operating condition are adapted upon the occurrence of such condition automatically to initiate a shutting down programme.

15. A control system as claimed in any preceding Claim, applied to a vapour generator having a plurality of fans for the supply of combustion air and a plurality of burners for discharging fuel to a furnace of the vapour generator, wherein burner control means are adapted, upon failure of a fan, to distinguish the operative burners from the inoperative burner or burners if any and to effect a reduction in the number of operative burners to a value suited to the number of fans in operation.

16. A control system as claimed in Claim 15, wherein a number of fuel pulverising mills are arranged to supply respective burners or groups of burners and the burner control means are adapted to distinguish the operative mills from the inoperative mill or mills if any and to effect reduction in the number of operative mills to a value suited to the number of fans in operation.

17. A control system as claimed in any preceding Claim, wherein a control device in response to a signal representative of the value of a variable and in accordance with a desired set value is adapted to effect regulation of the variable, and the control device is provided with set point varying means by which the set point can be varied by the control system in accordance with the coded programme being followed.

18. A control system as claimed in Claim 17, wherein the control device is adapted to exert a proportional and/or integral and/or differential control upon the variable derived from the error between the value of the variable and the set value.

19. A control system as claimed in Claim 17, or Claim 18, wherein a computing section of the control system directly associated with the storing means is linked to the control device by means providing the computing section with information as to the value of the variable and the set value of the control device.

20. A control system as claimed in Claim

17, Claim 18 or Claim 19, wherein a signal representative of the value of a second variable and a signal representative of the value of a third variable are fed to an analogue computer and a signal suitably compounded from the two signals is fed to the control device as the first variable.

21. A control system, as claimed in any preceding claim adapted to control external surface cleaning apparatus, including variable-responsive means arranged to be influenced by a variable the value of which depends upon the state of the external surfaces to be cleaned the control system being programmed by means of the coded programme in the storing means to compare the variable value with a predetermined value and in the event of the comparison being such as to indicate the need for cleaning to effect operation of the cleaning apparatus.

22. A control system as claimed in claim 1 and including analogue computer and local controller facilities arranged substantially as shown in, and adapted to operate substantially as hereinbefore described with reference to, Figures 20 and 21 of the accompanying drawings.

For the Applicants,
A. C. PRICE,
Chartered Patent Agent.

PROVISIONAL SPECIFICATION
No. 26069 A.D. 1958

# Improvements in Automatic Control Systems for Vapour Generating Plant

We, BABCOCK & WILCOX LIMITED, a British Company, of Babcock House, 209/225, Euston Road, London, N.W.1, do hereby declare this invention to be described in the following statement:—

This invention relates to control systems. In the use of a modern high-capacity vapour generator for supplying steam at high pressure to a turbine in a power station the starting up of the vapour generator and turbine in a manner ensuring safety of the plant is a complicated process calling for skilled and experienced operators able to act quickly and with judgement upon the occurrence of abnormal conditions. The shutting down of the vapour generator likewise requires skill and experience and particularly under emergency conditions may demand immediate and correct action. If, during starting up or shutting down an operator fails to take correct action sufficiently quickly, or at all, or exerts a wrong control, the possibility arises that the plant may be rendered unavailable for a long period of time and the resultant damage may be very costly to repair.

The modern high-capacity vapour generator utilises as firing means a considerable number of burners which may, for example, be oil burners or pulverised fuel burners of which different burners or groups of burners are supplied with pulverised fuel from respective mills and commonly the combustion air is supplied by a plurality of forced-draught fans and a plurality of induced-draught fans. In the event of failure of a fan, operation of the vapour generator may be continued at reduced load, but, inasmuch as the reduced combustion air supply may result in flame instability if all burners are retained in operation, the necessity arises of shutting down a burner or burners. This would be a simple requirement were it not for the fact that a burner or burners may be out of operation and must not be selected for shutting down. Consider, for example, the case of a pulverised fuel-fired generator having a number of pulverising mills of which at least one is a reserve mill, whilst the burner shutting down is to be effected by terminating operation of a mill or mills. Clearly a mill or mills other than a reserve or inoperative mill must be chosen for shutting down. Whilst in theory this difficulty may be overcome by the use of suitable interlocks, as the number of mills is increased the complication becomes so great that interlocking is hardly a practical solution.

During operation of a vapour generator fired with a fuel containing solid incombustible matter, the necessity arises of cleaning exterior heat exchange surfaces from time to time. The cleaning may be accomplished by a system of blowers or shot cleaning may be used in an upright pass containing convection heat exchange surfaces. Whilst in general the blowers are power operated and subject to automatic control to effect the actuation in proper sequence, the initiation of the cleaning operation calls for the attention and judgement of an operator. If on the one hand the operator effects cleaning of the surface too infrequently, the boiler efficiency suffers through a reduction in the effectiveness of the heat transfer surfaces. If on the other hand cleaning of the surfaces is carried out too often, energy is uselessly dissipated in the cleaning medium and there is unnecessary wear on the cleaning apparatus.

The present invention includes a control system adapted to start up or shut down a vapour generator, wherein the system includes storing means arranged to contain a coded programme and adapted to carry out the programme by transmitting in succession signals each expressed as a particular sequence of two different states.

Suitably, besides the storing means the con-

trol system includes means for giving electric pulses at constant frequency and circuits of suitable known form such as " or " circuits, " and " circuits, " not " circuits and delay circuits. Storing means of any suitable form or forms may be used, for example, storing means of the magnetic drum or magnetic tape type or of the staticisor type.

If desired, a programme may comprise a basic programme and an auxiliary programme or auxiliary programmes which may be chosen or applied according to circumstances.

Advantageously, the storing means contains a plurality of coded programmes, one for starting up from cold, at least one for starting up from a hot condition, one for a normal shut down and one for an emergency shut down.

The storing means may also contain a programme appertaining to normal running operation of the power plant.

Suitably, provision is made for effecting programme modification by permit means arranged to store permit signals and adapted by transmitting signals to permit a programme to proceed notwithstanding that states or conditions of respective elements of or associated with the vapour generator are unsatisfactory or the elements are withdrawn from operation.

Suitably, a programme includes testing signals and sensing means are arranged to effect signals indicative of states or conditions of the vapour generator or of elements of or associated therewith and comparison means are adapted to compare the testing signals and the comparison signals and in the event of the state or condition being unsatisfactory to effect stopping of the programme or rectification of the state or condition by a regulating action or by modification of the programme as may be appropriate. The sensing means may be of divers forms, but, by way of example, an electric contact may be closed only when a particular member is properly positioned. If then, in accordance with the programme two impulses are transmitted simultaneously one directly and the other indirectly through the said contact to an " and " circuit, the said circuit will distinguish whether the member is correctly or incorrectly positioned and will accordingly exert an appropriate control.

Provision is made for checking the state of elements such as gauges, drains or fuel containers. Thus, the position of boiler drain valves, or blow-down valves, or access doors may be effected by sensing contacts associated with the valves or doors. Alternatively, a check that the access doors are closed may be effected by pressurising the furnace chamber and gas passes by means of the forced-draught or primary air fans, a pressure responsive relay being arranged to close sensing contact only if the pressure rises to a predetermined value. Superheater draining valves may be automatically actuated and controlled by measuring with thermocouples the temperatures of the superheater tubes to determine when the tubes are free of condensate. The water level gauges may be checked through a comparison of the levels indicated by several gauges. A correct operation of the drains associated with a level gauge may be checked by automatically opening and shutting the steam and water connections and sensing the temperatures at the outlets from the drains as registered by thermo-couples connected thereto. Fuel containers may be checked as regard their contents, by means of level indicators of suitable form. Such checking of the level of fuel in coal bunkers and bins, or oil in tanks, will be automatically carried out before initiation of a firing sequence.

Advantageously, means are adapted when a transmitted programme order is not obeyed to give an indication of the particular failure and stop the programme if continuance of the programme might lead to a dangerous condition, but if the programme may safely be continued merely to give an indication of the failure.

Suitably, automatic printing means are arranged to show in print at least those matters in relation to elements of or associated with the vapour generator which are found during the carrying out of a programme to require consideration or attention. For example, a discrepency in the level indicated by one of the level gauges as compared with the level shown by other gauges, or the incorrect positioning of a drain or blow-down valve or access door would be shown in print.

Advantageously, the system is arranged to control automatic printing means adapted to print out the orders transmitted in accordance with a programme, the time when an order is given or obeyed and in a distinctive manner, as by offset printing, any failure to obey an order.

In one form of control system in accordance with the invention a starting up programme provides for the lighting of burners or groups of burners in sequence and upon failure of one burner or group of burners in the sequence to light up a control is exerted to light the next burner or group of burners if any in the sequence.

Thus, in one application, the starting up programme provides for the lighting of lighting up burners in sequence and the subsequent lighting of pulverised fuel burners or groups of pulverised fuel burners in sequence and selection of a pulverised fuel burner or group of pulverised fuel burners for lighting up is made only if the corresponding lighting up burner is in operation.

Continuous flame monitoring of the lighting up and of the pulverised fuel burners ensures safe operation by discontinuing the fuel supplies and purging the furnace in the event of

complete flame failure.

During starting up or shutting down, temperature responsive means are adapted to control firing rate in order suitably to limit gas temperature in the neighbourhood of superheater tubes. In this way the gas temperature leaving the furnace or entering the superheater is limited to a value suitable for the design metal temperature of the superheater tubes.

Furthermore, in a natural circulation boiler, during starting up or shutting down, means responsive to metal temperature at different locations on the separator drum walls are adapted to control firing rate in order suitably to limit temperature differences in and consequent stressing of the drum metal. The positions at which thermo-couples are positioned at locations along and around the drum are chosen in order that avoidance of excessive stressing of the drum material may be ensured. If, inadvertently, temperature difference in the material of the drum tends to increase beyond a safe limit a control is exerted whereby the drum is automatically flooded from the feedwater source.

The system is also arranged to control starting up of a turbine connected to receive vapour from the generator. Thus, provision is made for effecting heating up and draining of the piping leading from the vapour generator to the turbine and for checking that the piping has been heated and drained. Provision is also made for effecting heating up of, and generally safeguarding, the turbine during the starting up period, and for placing the turbine in operation when the preparation of the turbine and the preparation of the vapour generator are complete. Suitably, provision is also made whereby, the turbine having been started up, an alternator driven by the turbine is synchronized and connected to an electrical supply system.

In the case of a once-through boiler, the turbine speed will be suitably limited and regulated by control of a valve in the steam line leading to the turbine and the dumping valve will be controlled in dependence on measures of temperature of the boiler tube metal in order to safeguard the boiler tubes from overheating.

Means responsive to a particular operating condition are adapted, upon the occurrence of such condition, automatically to initiate a shutting down programme. Thus, for example, in the event of failure of feed pressure and failure of a standby feed pump to come into operation, a shut down programme would be initiated. Simultaneously, in the event of the turbine being tripped out, the firing rate would be reduced to a minimum and, in the absence of return of the load demand, a shut down programme would be initiated.

When a vapour generator is provided with a series or parallel arrangement of superheater and reheater with control or by-pass dampers, the latter would, during starting up or shutting down, be automatically set to protect the reheater metal.

A programme appertaining to normal running operation may appertain to such matters as shutting off burners upon fan failure; the automatic sampling of steam purity and dissolved solids in the boiler water and the application of the results to control an intermittent or continuous blow-down; the periodic checking of the pressure on the grinding rings of pulverising mills and the recording of the pressure; or the checking and recording of the weight of balls in an idle tube mill or the weight of coal in an operative tube mill; and the control system may operate together with the locally positioned controllers and relays of conventional vapour generator control apparatus. Preferably, however, the control system is also arranged to effect control of the operation of the vapour generator during normal working thereof. Thus, the control system will effect regulation of steam pressure and the temperature of superheat or reheat.

With regard to the control of superheat or/and reheat, advantageously the control system is adapted to exert alternative controls such that regulation to give maximum efficiency is obtained if this can be done with safety, but that otherwise regulation to ensure safety is exerted. By way of example, in a vapour generator operating with gas recirculation and having a superheater and a reheater, each with an attemperator, and a by-pass to the reheater, the gas recirculation may be controlled to regulate superheat temperature should that tend to be low or reheat temperature should that tend to be low with the dampers closed, the reheat temperature being limited, if necessary, by opening of the by-pass dampers or, if the reheat temperature tends to become too high for safety, by attemperation and the temperature of superheat being limited by attemperation. If, however, the necessity for increased gas recirculation in order to maintain the temperature of superheat is indicated, for example, directly as by a measure of the first superheat temperature or indirectly as by an indication of the reduction in the supply of attemperating fluid to a low value, and such increase would lead to undesirable or unsafe conditions in connection with the resuperheated steam, as indicated, for example, directly by a measure of the temperature of reheat or indirectly by a positioning of the dampers in the fully open positive or of a value to initiate attemperation, then the gas recirculation will be controlled to maintain an optimum temperature of reheat. There is thus great flexibility of control.

The invention also includes a control system for a vapour generator having a plurality of fans for the supply of combustion air and a plurality of burners for discharging fuel to a furnace of the vapour generator, wherein burner control means are adapted, upon failure

of a fan, to distinguish the operative burners from the inoperative burner or burners if any and to effect a reduction in the number of operative burners to a value suited to the number of fans in operation. In this way flame stability is ensured.

Thus, in one application, a number of mills are arranged to supply respective burners or groups of burners and the burner control means are adapted to distinguish the operative mills from the inoperative mill or mills if any and to effect reduction in the number of operative mills to a value suited to the number of fans in operation.

In the case of a vapour generator arranged to be fired by alternative fuels, advantageously, the control system is adapted upon failure of one fuel supply automatically to exert control for bringing into operation another fuel supply.

The invention also includes a control system, for a vapour generator external surface cleaning apparatus, arranged to operate by signals effected by two different states and adapted automatically to initiate operation of the cleaning apparatus.

Suitably, variable-responsive means arranged to be influenced by a variable the value of which depends upon the state of the external surfaces to be cleaned are adapted when the value of the variable is such as to indicate the need for cleaning to effect operation of the cleaning apparatus.

The variable may, for example, be heat transfer to the fluid flowing through the tubes to be cleaned, or gas temperature at the outlet from a component of the vapour generator, for example, an economiser or air heater.

Suitably, a measure of the variable is compared as by subtraction from a standard value, and provision is made whereby the said value indicative of the need for cleaning is varied to compensate for different operating conditions of the vapour generator. Thus, the said value may be corrected for load, for the number of burners in operation and for other pertinent conditions such as rate of gas recirculation. As previously indicated, the cleaning may be carried out by means of blowers or by blowers acting in conjunction with shot cleaning apparatus. Some of the surfaces may also be cleaned by water washing.

The control system may also be arranged to select and bring into operation in proper sequence various blowers in other elements of the cleaning apparatus.

The control system may include a digital computer to which different programmes may be fed at will, for example, by means of punched tape. The computer in turn may effect punching of tape in order to control a teleprinter.

From the above description will be understood that the control system is adapted, by exercising a simple control such as the actuation of a press button switch, to effect starting up either from a cold state or a hot condition of plant comprising a vapour generator and a turbo-alternator or shutting down of the plant under normal conditions. The control system described is also adapted to effect emergency shut down either in response to an automatic control or upon depression of the press button. Furthermore, the control system is adapted to carry out all the controls normally necessary under running conditions. As a result the task of the operator is greatly eased, necessary emergency action is taken with great expedition and the danger of incorrect operation is lessened or avoided.

By way of example, a typical programme for the starting up of a vapour generator from cold will now be described:—

Before commencement of operation, equipment out of action must be isolated to prevent operation thereof and outstanding permits are fed by a coded signal into the control system, a suitable test signal being given whereby sensing means shows whether this necessary action has been taken. If the permits have not been fed or if an indication that there are no permits has not been given, the programme is stopped so that the omission may be rectified.

A test is made as to whether all drain and blow-down valves are shut, and if any drain or blow-down valve is open, the programme is stopped and such state is indicated by the teleprinter and must be rectified by the operator, whereupon depression of the press button restarts the programme and the test is remade.

A test is made as to whether all access doors or the like are shut. In the event of any door being open such state is shown by the teleprinter and the programme is stopped. After closure of the door or doors by the operator and depression of the press button, the programme is restarted and the test repeated.

All superheater drain valves and air vent valves are automatically opened.

Two sequences in parallel are initiated. In one the feed pump is started, the feed pressure is checked, the water level is adjusted to 1" from the bottom of the glasses of the water gauges and the correct operation of the gauges is tested. In the other sequence, a full oil tank is selected, the oil fuel pumps are started and valves are adjusted for controlling heating of the oil by the oil heater.

Dampers are closed, such as induced-draught fan dampers, forced-draught fan dampers, burner registers, tempering air dampers and primary air dampers. If any damper fails to close, the programme is stopped, the operator closes the damper and depression of the press button effects rechecking of the closures of the dampers upon restarting of the programme.

The induced-draught fans are started up. If

both fans fail to start such condition is indicated by the teleprinter and the programme is stopped.

Both forced-draught fans are started up. If one induced-draught fan or one forced-draught fan fails to start such condition is indicated by the teleprinter but the programme is continued.

Two steps are carried out in parallel. In one oil is admitted for the lighting up burners to the front and the usual purging is carried out. In the other step the oil burner registers are opened for the flow of secondary air. If any register fails to open this is indicated by the teleprinter and will act to prevent subsequently inclusion of the associated oil burner in the firing sequence.

The induced-draught and forced-draught dampers are adjusted to give flow through the vapour generator for five minutes, and from then on the furnace suction is maintained say at 0.3" water gauge. The forced-draught output damper opening is controlled in steps relative to the firing rate until the steam flow/air flow control is brought in.

Subsequently, register dampers or other individual dampers of the oil burners are automatically actuated in dependence on load and/or time.

The first oil burner of a sequence is selected and the secondary air register is opened. If the particular burner cannot be selected it is indicated by the teleprinter and the next burner in the sequence is selected. The oil pressure is adjusted. A test is made to determine whether the superheat inlet gas temperature is below a predetermined value, say 900°F. If it is not, a control is exerted to reduce the firing rate by adjustment of oil pressure. Another test is made to determine whether differential temperature in the drum metal is below a predetermined value, say 100°F. If it is not, a control is exerted to reduce the firing rate by adjustment of oil pressure. If both temperatures are below the predetermined values a test is made to determine whether the burner is operating at a predetermined output, for example 50% of its output. If it is not, a control is exerted to increase the firing rate by adjustment of oil pressure. If the output of the burner is as desired, a test is made to determine whether all the available oil burners have been selected. If they have not, then a further burner is selected and the cycle is repeated until all the available oil burners are in operation.

After the firing rate of the operative oil burners has been increased to the desired value and pressure has been produced within the vapour generator, the drum vents are closed.

When the superheater tubes are cleared of condensate, the superheater drain valves, with the exception of the final outlet drain valve, are closed. When all the superheater tubes are cleared of condensate, the above mentioned limit of the furnace exit gas temperature is no longer necessary.

The oil firing rate has gradually been increased and before the maximum rate of oil firing is reached the pulverised fuel system is checked and prepared, the first mill to be selected being warmed up. When the first mill has been brought into operation, the next in sequence is prepared. Thus, when oil firing has been increased to the desired extent and other conditions are satisfactory the first mill of a sequence is selected. Such mill cannot be started unless the appropriate lighting up burner is in operation. Throughout the operation, the oil burner flames have been monitored and from now on the pulverised fuel flames are monitored.

From now on and until the boiler is on load the firing rate is restricted suitably to limit the differential temperature of the drum metal. The mill output is increased to a suitable degree and at the same time the output of the oil burners is reduced.

Other mills are selected and are brought into operation as is necessary.

Minimum load is maintained with oil firing in order to ensure flame stability.

Before opening the main stop valve, blowdown is effected to give a level of half gauge glass.

The steam range drain valves and the bypass valve are closed and the main stop valve is opened, the latter valve being controlled from the turbine.

When the vapour generator is on load, the economiser recirculation valve and the drain valve at the outlet of the superheater are closed.

The firing rate is increased as required by the turbine.

When the vapour generator is up to pressure the firing rate is controlled in dependence upon the pressure.

When the output of the vapour generator reaches a suitable proportion of the maximum load, means responsive to the ratio of the steam flow to combustion air flow are rendered effective to control rate of firing.

By way of example, the portion of the programme dealing with the introduction of additional burners is now described in greater detail.

A flame sensitive device, which may be a photocell, or means responsive to the sound produced by an operating burner, produces an electrical output which is passed to a digitiser. The output from this is in the form of a train of pulses representing the number of burners in operation, suitably on a binary scale.

This number is passed to a store which may be a rotating magnetic drum, a set of magnetic cores, or a group of bi-stable trigger valves.

The maximum number of burners is also stored in a similar manner. Under the direction of a timing control these two numbers are compared by inverting one of them and adding. Suitable valve or transistor circuits are well known for performing these functions.

So long as the number of burners in use is less than the maximum, pulses representing the difference are fed to a suitable location in the store. When the burners in service reach maximum output, a number representing the oil flow to a burner having been compared with a preset number indicative of the maximum flow in a similar manner to that used to determine when the maximum number of burners is in operation as described above. This part of the store will be read, and, if not zero, will bring in an additional burner by means of relays operating on the igniter, register motor drive, and oil supply valve motor.

If the number stored is zero, all burners are in use, and this state may be recorded by suitable means, as, for instance, in the form of a punched paper tape fed to a teleprinter.

It may be desirable to introduce an appropriate time delay between, for instance, the operation of the igniter and the oil supply valve. A suitable means of obtaining such a delay is a loop circuit with a preset counter. The counter is reduced by unity at every circuit of the loop and when the initial number is reduced to zero the operation of the relay is initiated.

From the above description will be understood the nature of the programme required for shutting down the vapour generator or controlling the normal operation thereof.

It will be understood that a particular sequence of operations may be carried out automatically by an auxiliary control unit the operation of which is initiated as a step in a programme contained in the storing means. There may be a plurality of such auxiliary control units appertaining to different sequences or sets of operations. By way of example, an auxiliary control unit may effect testing as to whether drain and blow-down valves are shut and as to whether all access doors or the like are shut and may effect opening of superheater drain valves and air vents; or an auxiliary control unit may effect sequencial operation of a number of sootblowers.

For the Applicants,
A. C. PRICE,
Chartered Patent Agent.

PROVISIONAL SPECIFICATION
No. 24813 A.D. 1959

## Improvements in Automatic Control Systems for Vapour Generating Plant

We, BABCOCK & WILCOX LIMITED, a British Company, of Babcock House, 209/225 Euston Road, London, N.W.1 England do hereby declare this invention to be described in the following statement:—

This invention relates to control systems and particularly to control systems for vapour generators. In the specification of our copending Patent Application No: 26069/58 is described a control system adapted automatically to start up or shut down a boiler or to effect control of boiler operation during normal working thereof. During the automatic control of a boiler and more particularly during starting up or shutting down thereof it may be necessary to vary the set point to which a variable such as steam pressure or steam temperature is regulated and an object of the invention is to enable this to be done.

Control systems for a vapour generator according to the present invention includes storing means arranged to contain a coded programme and adapted to carry out the programme by transmitting in succession output signals each expressed as a particular sequence of two different states and set point varying means responsive to an output signal are adapted to effect adjustment of the set point of a control device to a required value predetermined by programme or automatically calculated and the control device in response to a signal representative of the value of a variable is adapted to effect regulation of the variable.

An output signal may be automatically calculated by means of a digital computer forming part of the control system the computer in making the calculation utilising an input signal or input signals representative of the value of a variable or the values of respective variables in the operation of the vapour generator.

Advantageously the set point varying means are adapted to vary the value of an electric set point signal and the control device includes means for comparing the set point signal and an electric control signal the value of which is representative of the value of the variable.

Thus, in one embodiment, a device sensitive to a variable in the operation of the vapour generator, for example, a device responsive to pressure, rate of flow or temperature acting through a transducer, is adapted to effect transmission of a comparator of an electric control system representative of the value of the variable whilst an electric set point signal transmitted to the comparator is controlled by means of an adjustable rheostat driven by an electric motor under the control of a digital computer. When the set point

differs from the desired value determined by the setting of the rheostat, the comparator gives an appropriate output resulting in an output signal adapted to effect operation of means for effecting regulation of the variable, for example, in the case of rate of flow, operation of a valve or damper. The output of the comparator may be transmitted through means for adjusting sensitivity or proportional band and through means for imparting an integral or derivative characteristic to the output signal.

Suitably means are provided for giving a checking signal representative of the value of the set point and control means are arranged to initiate regulation of the set point when the value of the set point as shown by the checking signal differs from the desired value. Thus suitably control means in the computer responsive to the checking signal are adapted, if the set point as indicated by the checking signal differs from the required value as determined by a digital computer to effect the output signal necessary for the adjustment of the set point.

From the above description will be understood that the computer is provided with means for governing the regulator of a variable and hence the variable itself. A checking signal indicative of the actual value of the set point fed to the computer may be derived in any suitable fashion, for example, by means of a pneumatic-electric or other transducer.

In the operation of the vapour generator, the computer at an appropriate time or times senses the set point by means of a checking signal and having determined the actual value of the set point effects any necessary adjustment by means of the rheostat motor which suitably is a reversible electric motor adapted to run in the forward or reverse direction or to remain stationary under the control of the computer. Any variation of the set point results in operation of the regulating means to effect adjustment of the variable to the desired value.

Instead of utilising a potentiometer to adjust the set point, the set point may be adjusted in other suitable known manner, as by adjusting the pivotal point of a beam or the biasing force exerted by a spring.

For the Applicants,
A. C. PRICE,
Chartered Patent Agent.

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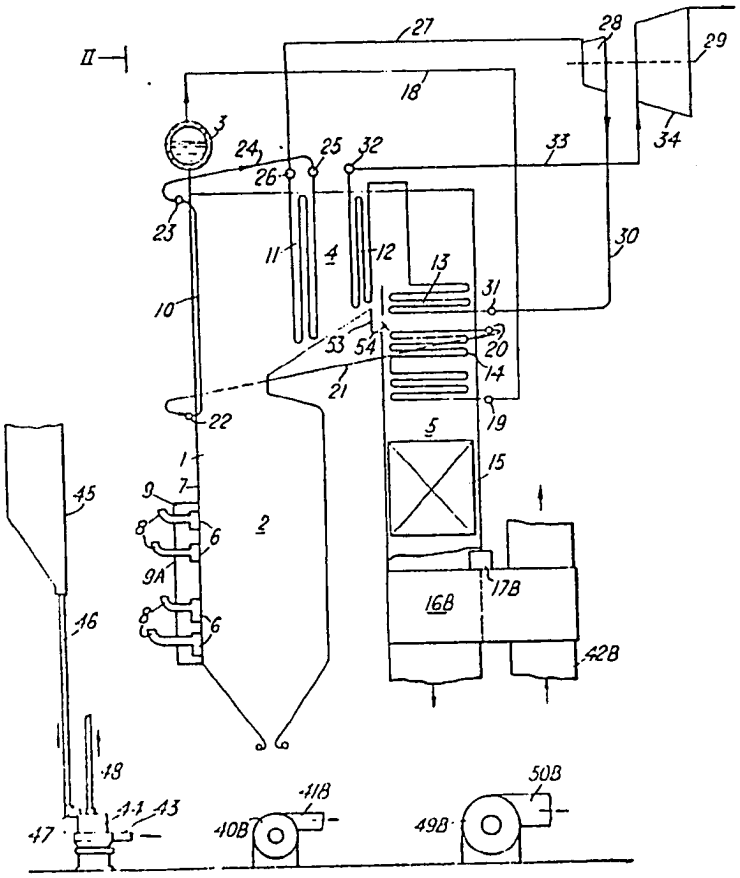
Sheet 1

Fig. 1.



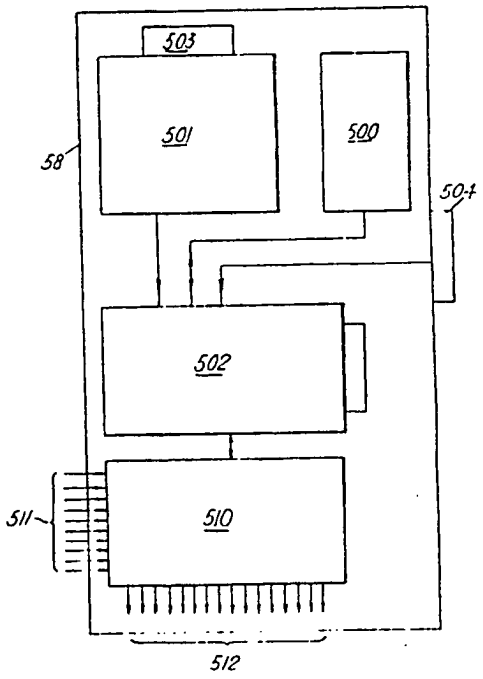
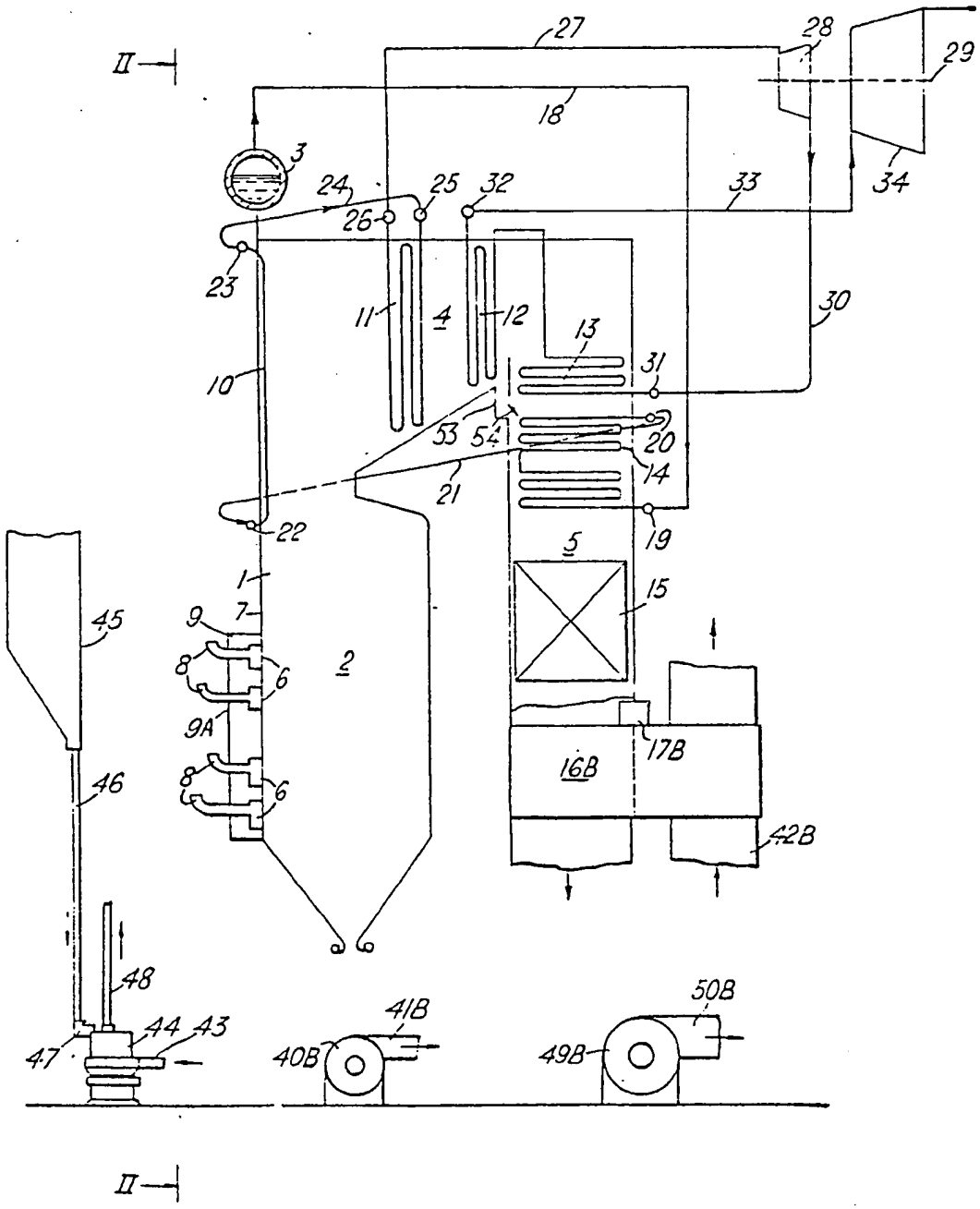
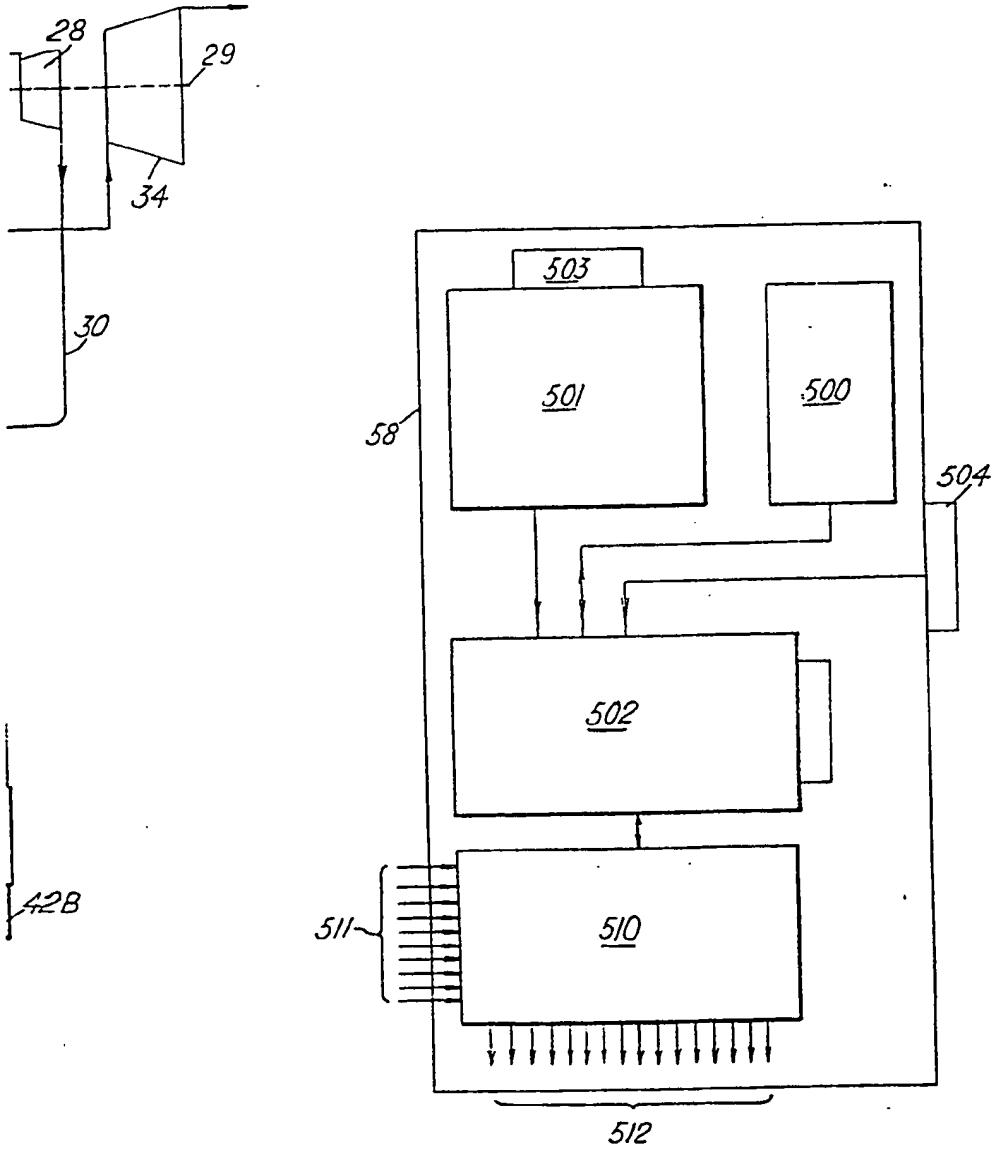



Fig. 1.



893251 COMPLETE SPECIFICATION
15 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 1

*Fig. 1.*



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Sheet 2

Fig. 3.

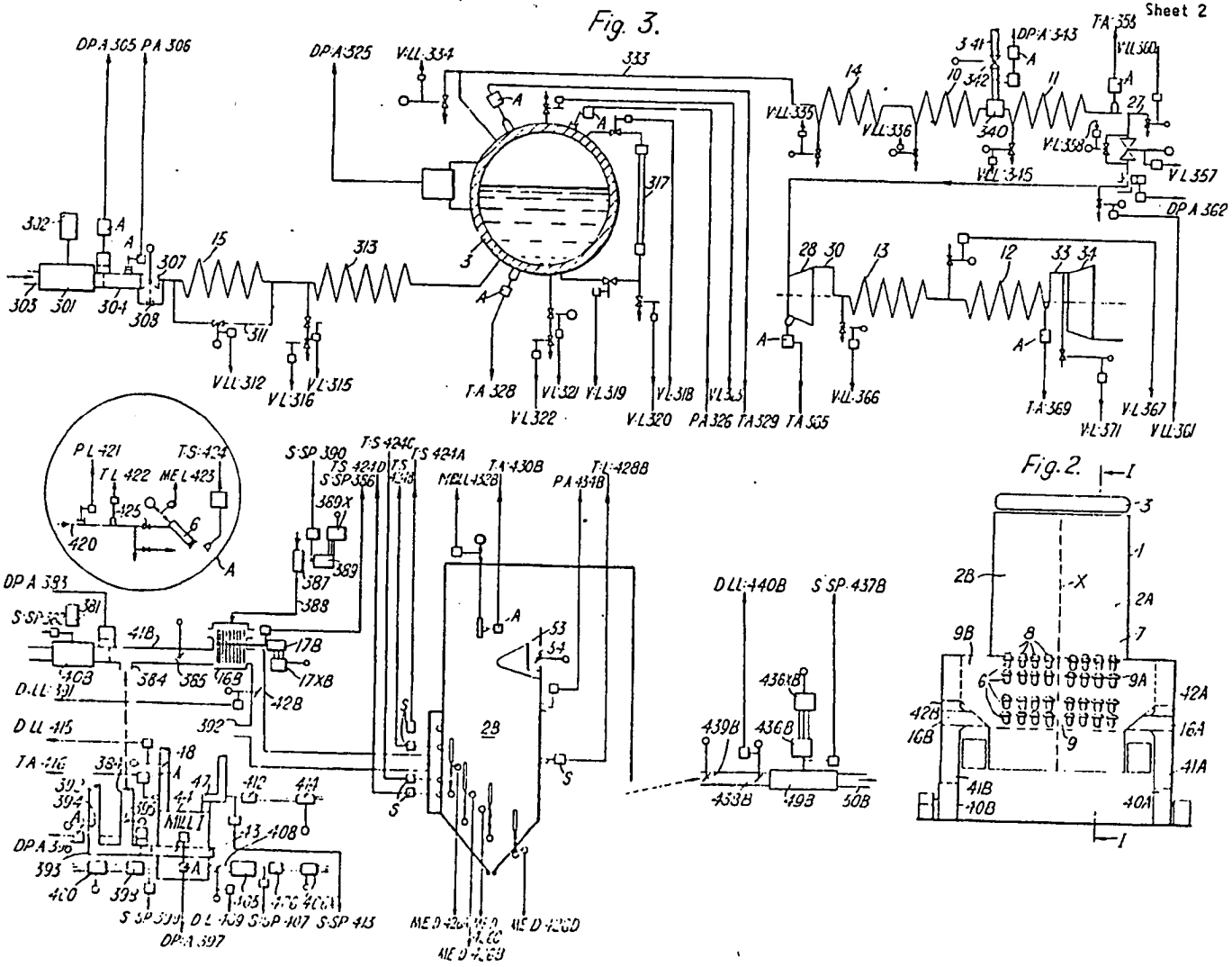


Fig. 3.

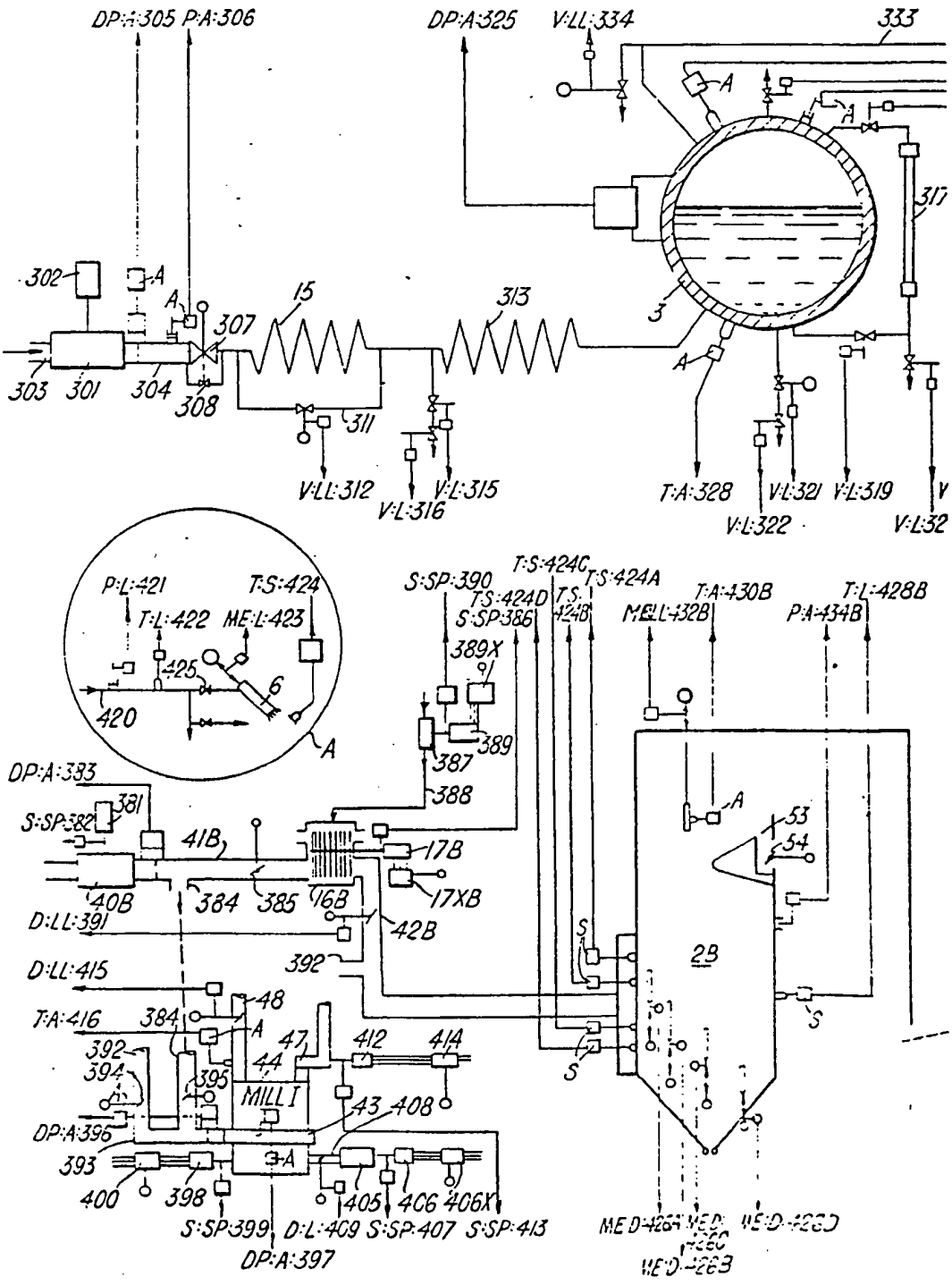
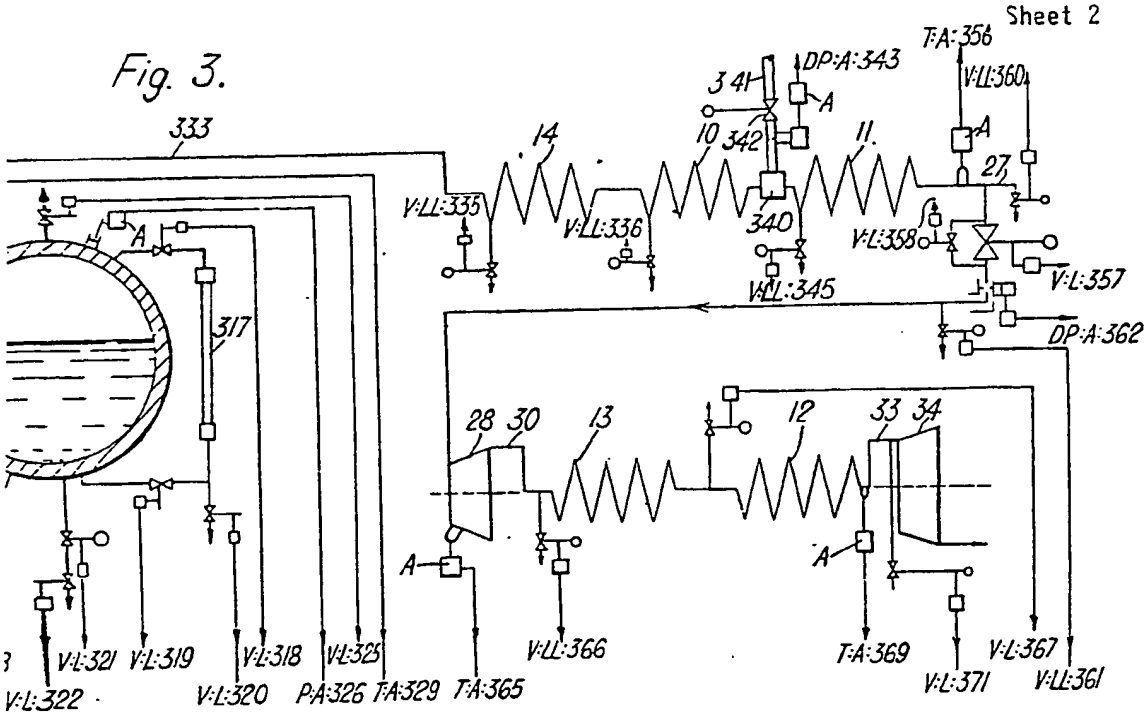


Fig. 3.



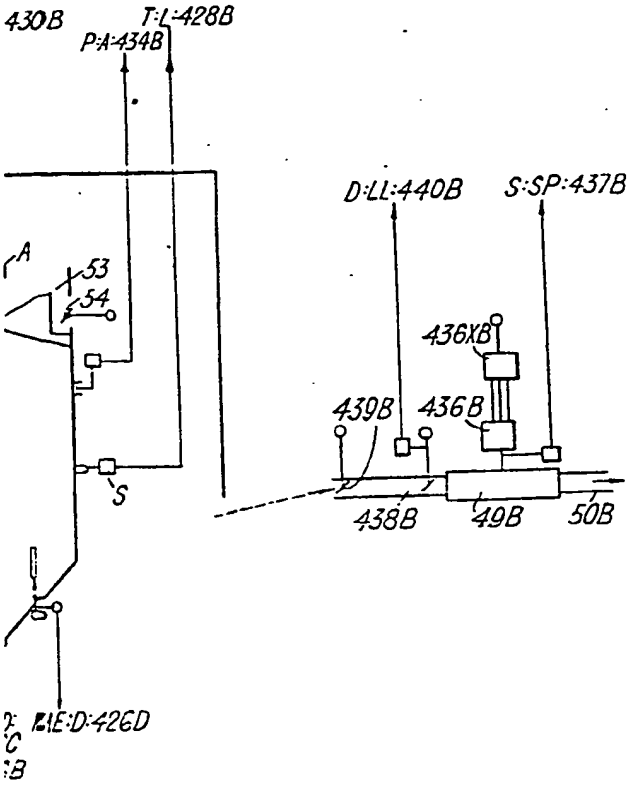
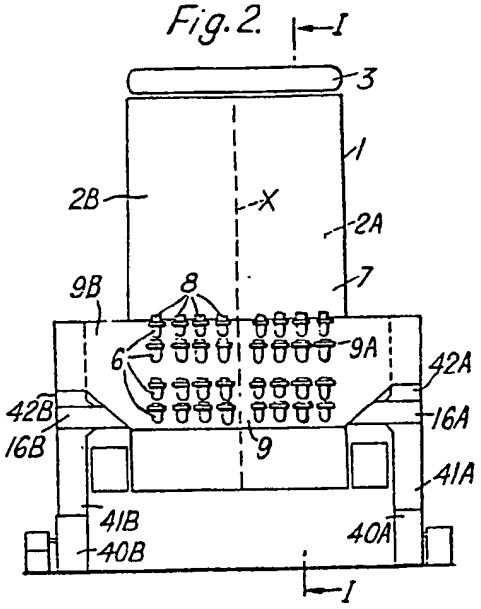




Fig. 2.



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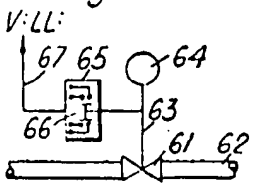


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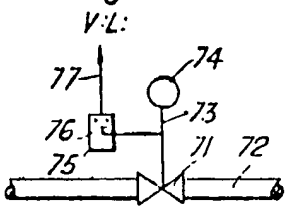


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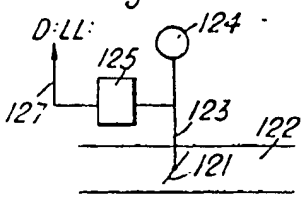


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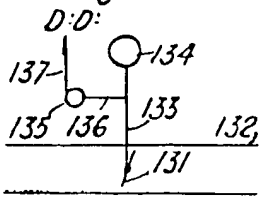


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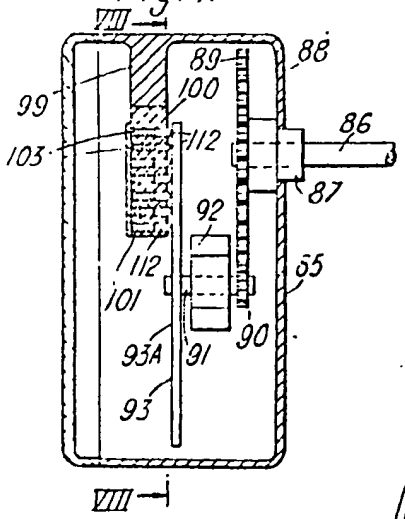


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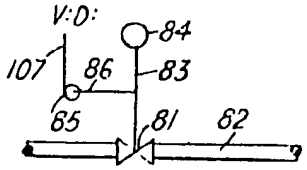


Fig. 8.

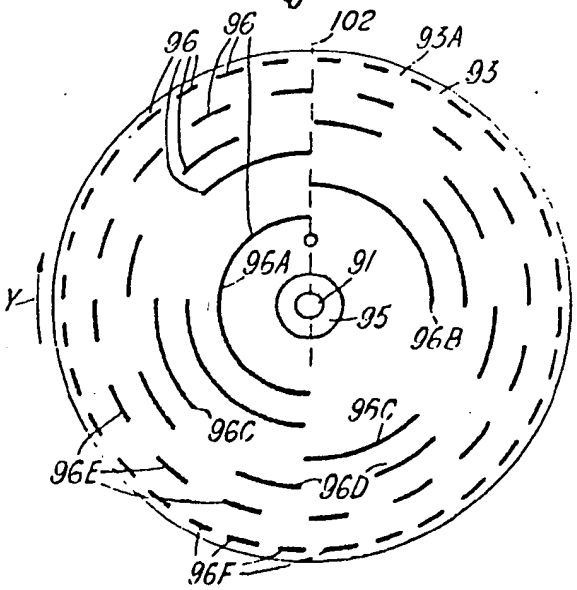

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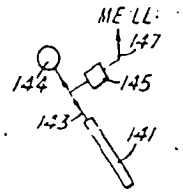
Fig. 11.

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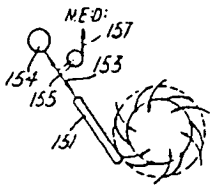


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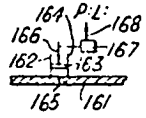


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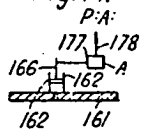


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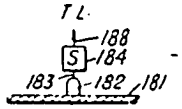


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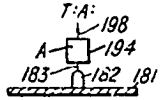


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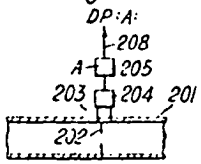


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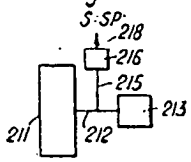


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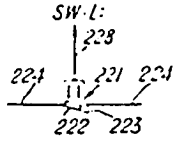


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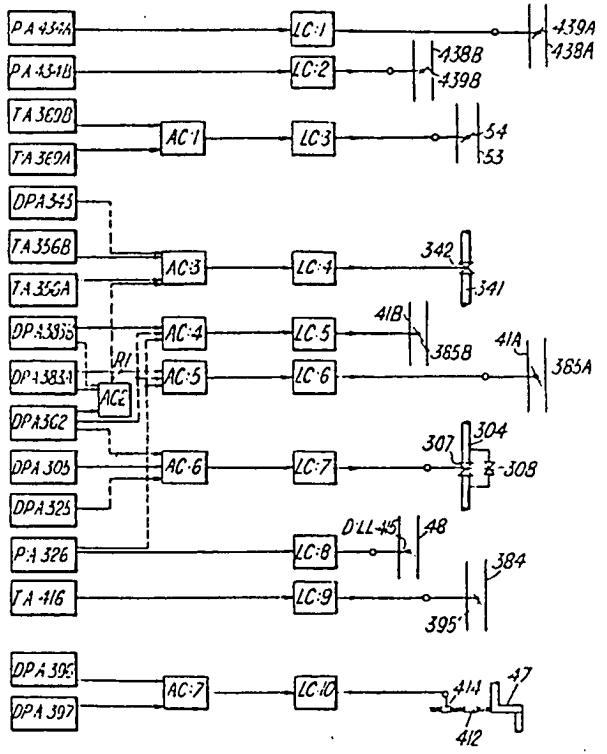


Fig. 11.

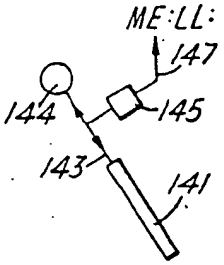



Fig. 12.

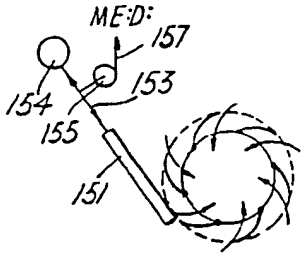
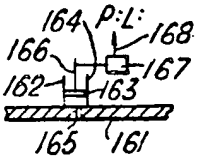



Fig. 13.

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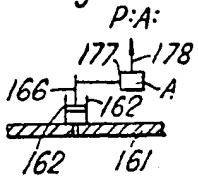


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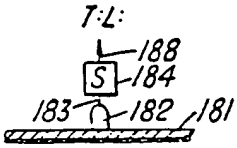


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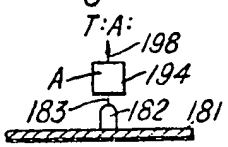


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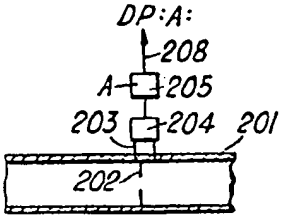


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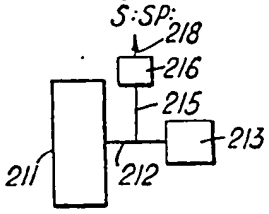


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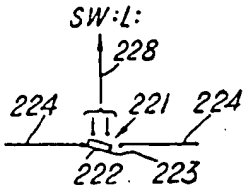


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P:A:434
TA:369
T:A:369
DP:A:34
T:A:356
T:A:356
DP:A38
DP:A38
DP:A36
DP:A:3C
DP:A3
P:A:32
T:A:41
DP:A:3
DP:A:3

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Fig. 20.

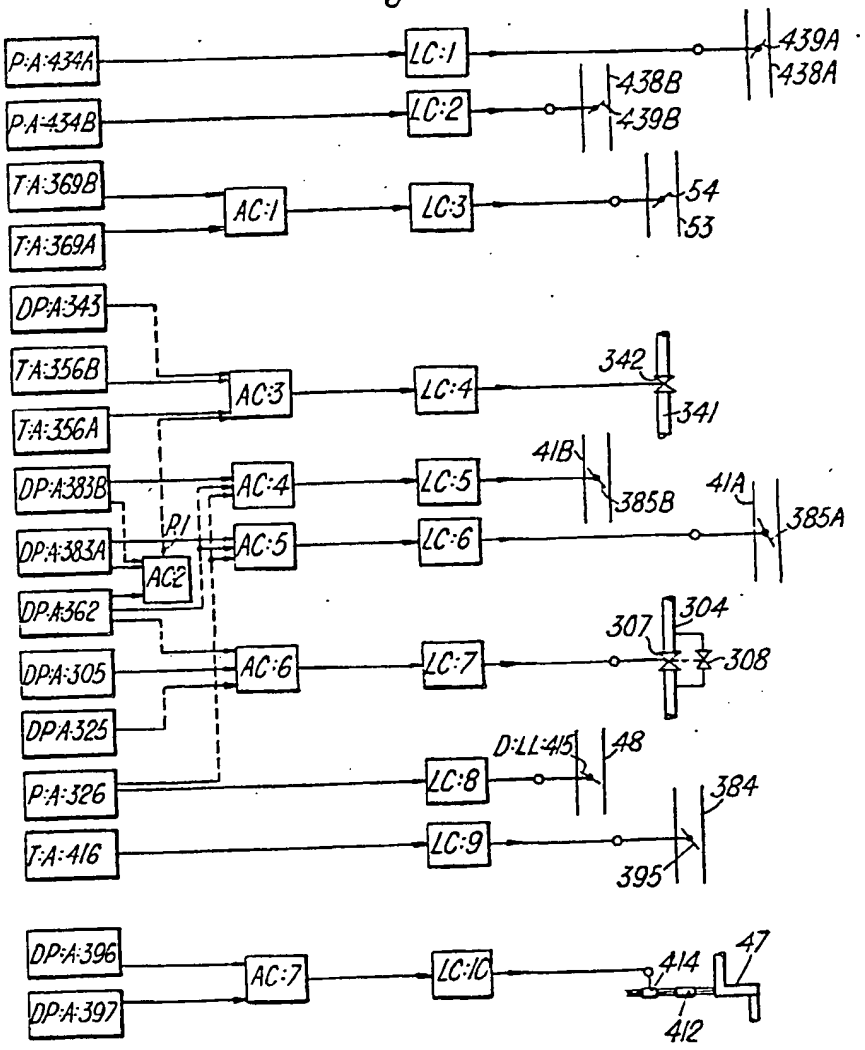

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Fig. 21.

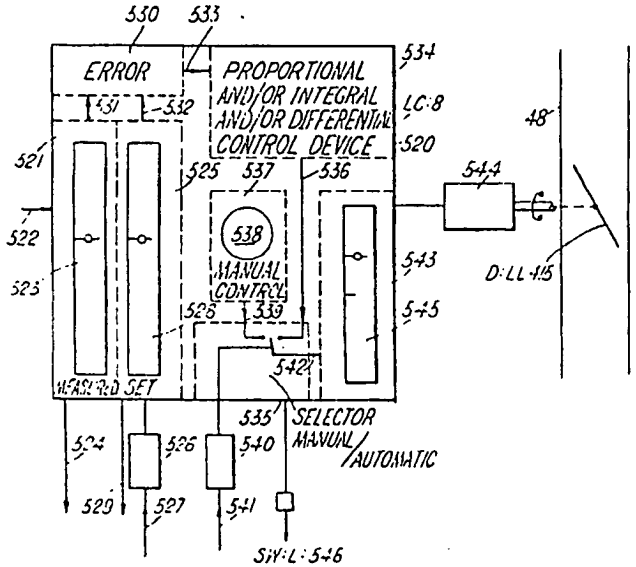
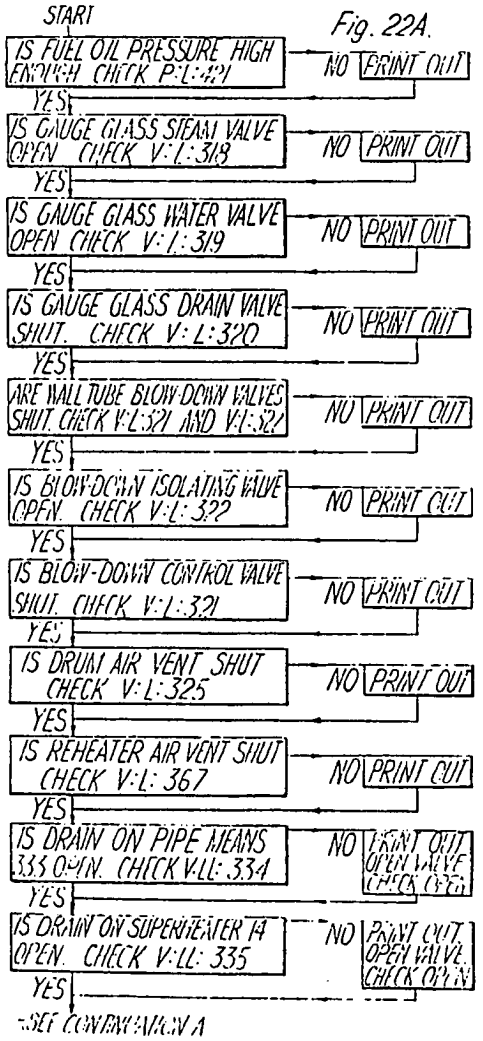



Fig. 22A.



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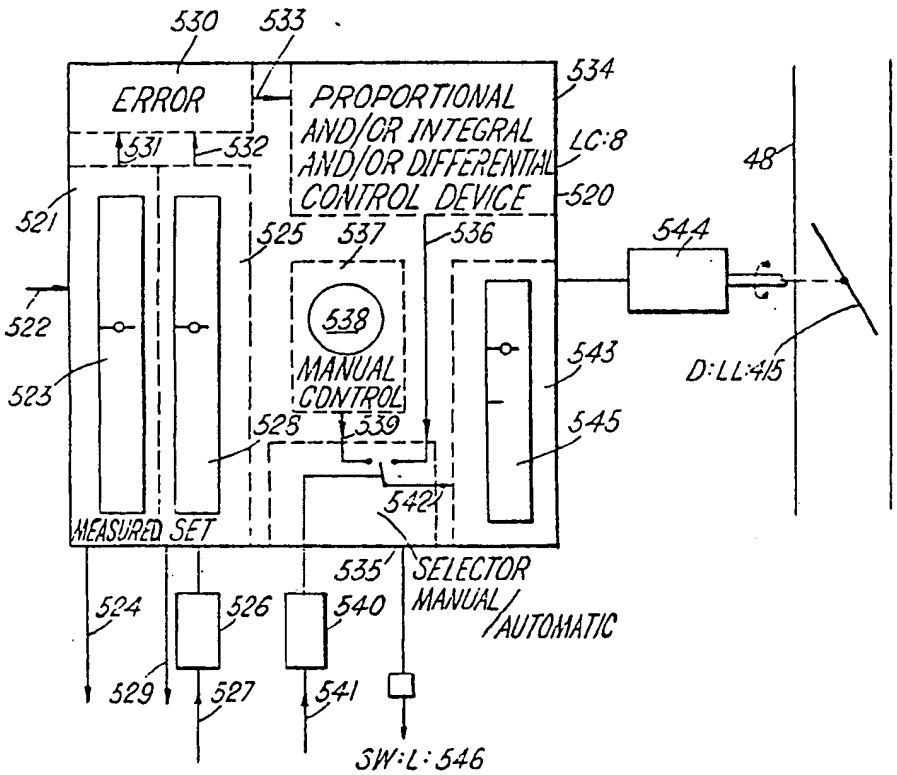


START

IS FUEL OIL F ENOUGH CHEC

YES

IS GAUGE GLA OPEN. CHECK

YES

IS GAUGE GLA OPEN. CHECK

YES

IS GAUGE GL SHUT. CHEC

YES

ARE WALL TUBE SHUT. CHECK V:

YES

IS BLOW-DOW OPEN. CHECK

YES

IS BLOW-DOW SHUT. CHECK

YES

IS DRUM AI CHECK V

YES

IS REHEATE CHECK V

YES

IS DRAIN O 333 OPEN. C

YES

IS DRAIN ON OPEN. CHEC

YES

-SEE CONTIN.

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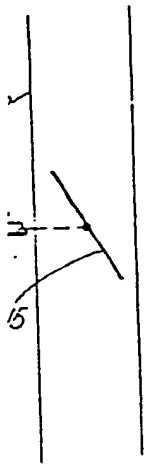
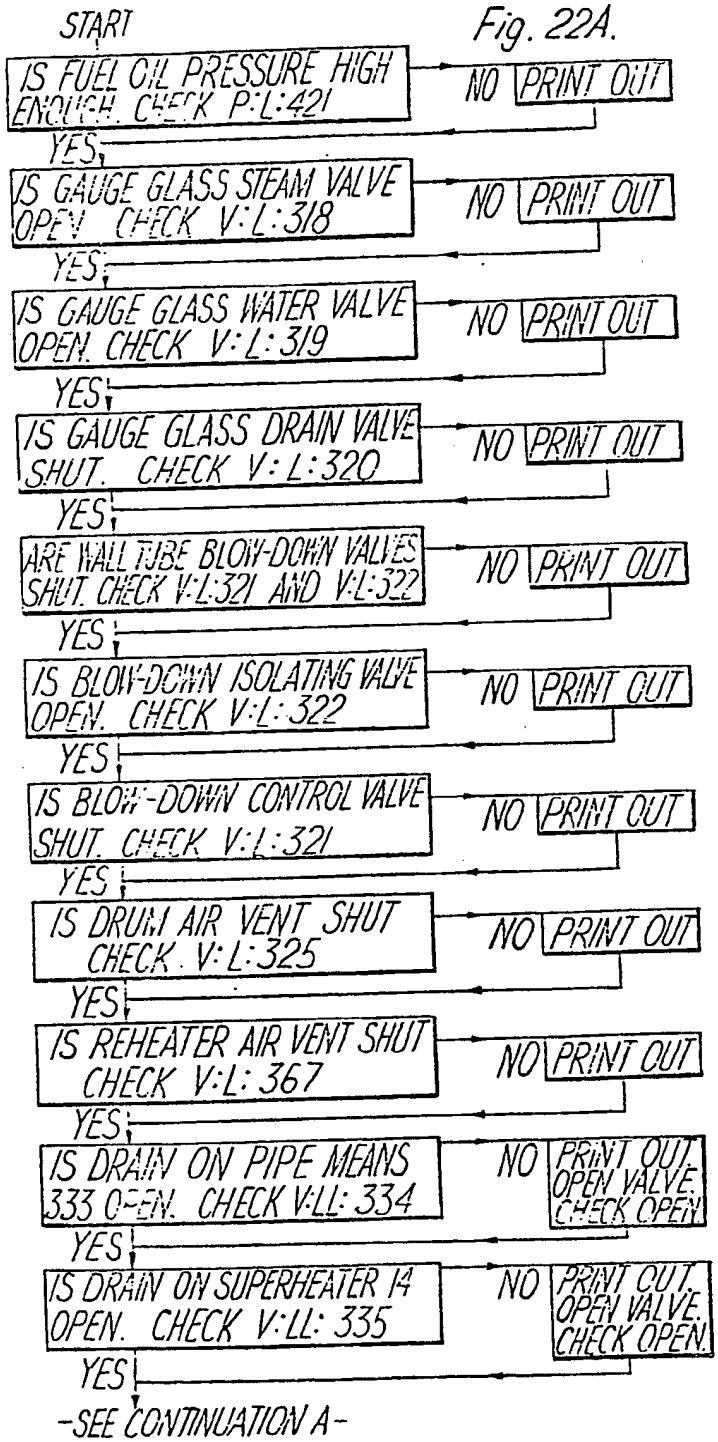
Fig. 22A.





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Sheets 8 & 9

Fig. 22B.

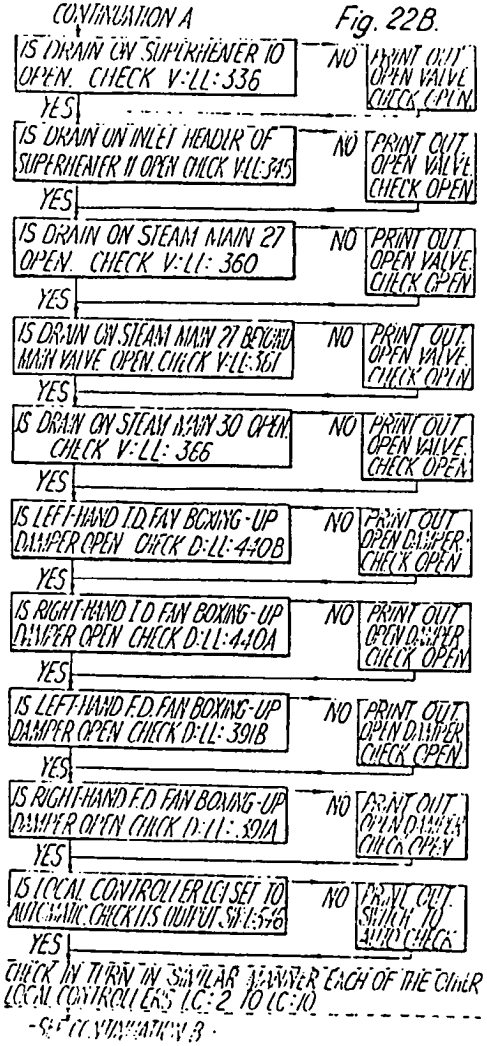



Fig. 22C.

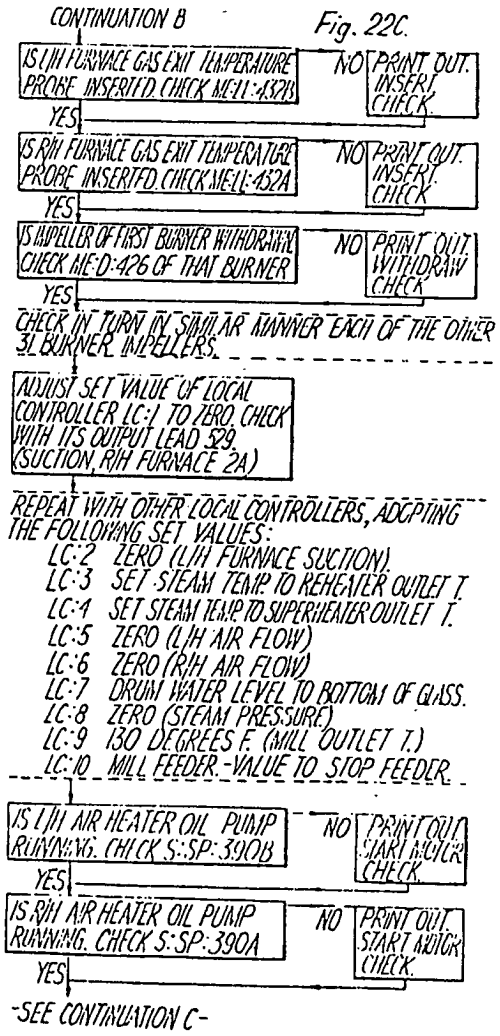
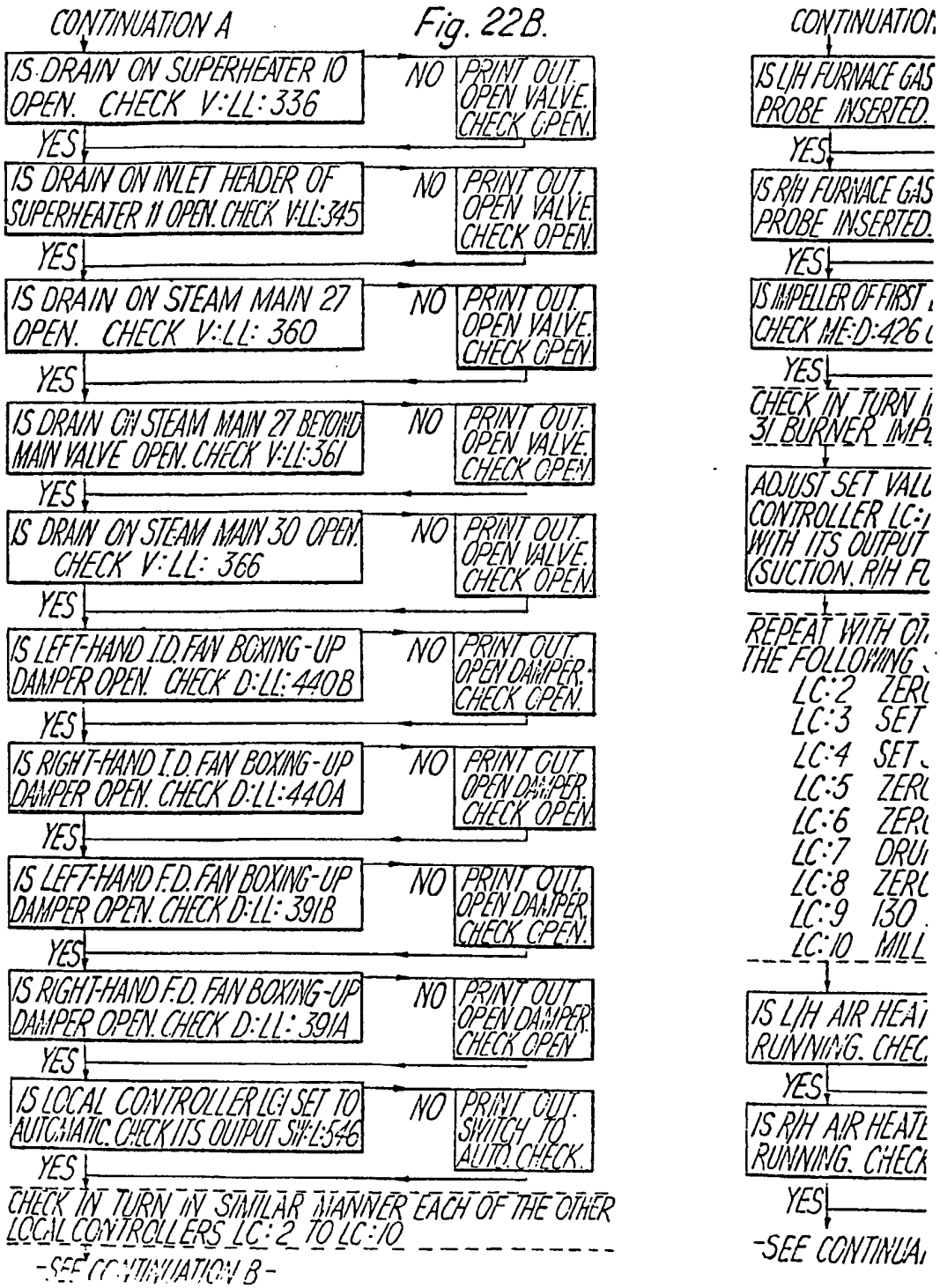


Fig. 22B.



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Sheets 8 & 9

22B.

PRINT OUT. OPEN VALVE. CHECK OPEN.

PRINT OUT. OPEN VALVE. CHECK OPEN.

PRINT OUT. OPEN VALVE. CHECK OPEN.

PRINT OUT. OPEN VALVE. CHECK OPEN.

PRINT OUT. OPEN VALVE. CHECK OPEN.

PRINT OUT. OPEN DAMPER. CHECK OPEN.

PRINT OUT. OPEN DAMPER. CHECK OPEN.

PRINT OUT. OPEN DAMPER. CHECK OPEN.

PRINT OUT. OPEN DAMPER. CHECK OPEN.

PRINT OUT. SWITCH TO AUTO. CHECK.

H OF THE OTHER

CONTINUATION B

Fig. 22C.

IS L/H FURNACE GAS EXIT TEMPERATURE PROBE INSERTED. CHECK ME:LL:432B — NO → PRINT OUT. INSERT. CHECK.

YES

IS R/H FURNACE GAS EXIT TEMPERATURE PROBE INSERTED. CHECK ME:LL:432A — NO → PRINT OUT. INSERT. CHECK.

YES

IS IMPELLER OF FIRST BURNER WITHDRAWN. CHECK ME:D:426 OF THAT BURNER — NO → PRINT OUT. WITHDRAW CHECK

YES

CHECK IN TURN IN SIMILAR MANNER EACH OF THE OTHER 31 BURNER IMPELLERS.

ADJUST SET VALUE OF LOCAL CONTROLLER LC:1 TO ZERO. CHECK WITH ITS OUTPUT LEAD 529. (SUCTION, R/H FURNACE 2A)

REPEAT WITH OTHER LOCAL CONTROLLERS, ADOPTING THE FOLLOWING SET VALUES:

- LC:2 ZERO (L/H FURNACE SUCTION).
- LC:3 SET STEAM TEMP. TO REHEATER OUTLET T.
- LC:4 SET STEAM TEMP. TO SUPERHEATER OUTLET T.
- LC:5 ZERO (L/H AIR FLOW)
- LC:6 ZERO (R/H AIR FLOW)
- LC:7 DRUM WATER LEVEL TO BOTTOM OF GLASS.
- LC:8 ZERO (STEAM PRESSURE)
- LC:9 130 DEGREES F. (MILL OUTLET T.)
- LC:10 MILL FEEDER. -VALUE TO STOP FEEDER.

IS L/H AIR HEATER OIL PUMP RUNNING. CHECK S:SP:390B — NO → PRINT OUT. START MOTOR CHECK.

YES

IS R/H AIR HEATER OIL PUMP RUNNING. CHECK S:SP:390A — NO → PRINT OUT. START MOTOR CHECK.

YES

-SEE CONTINUATION C-

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Fig. 22D.

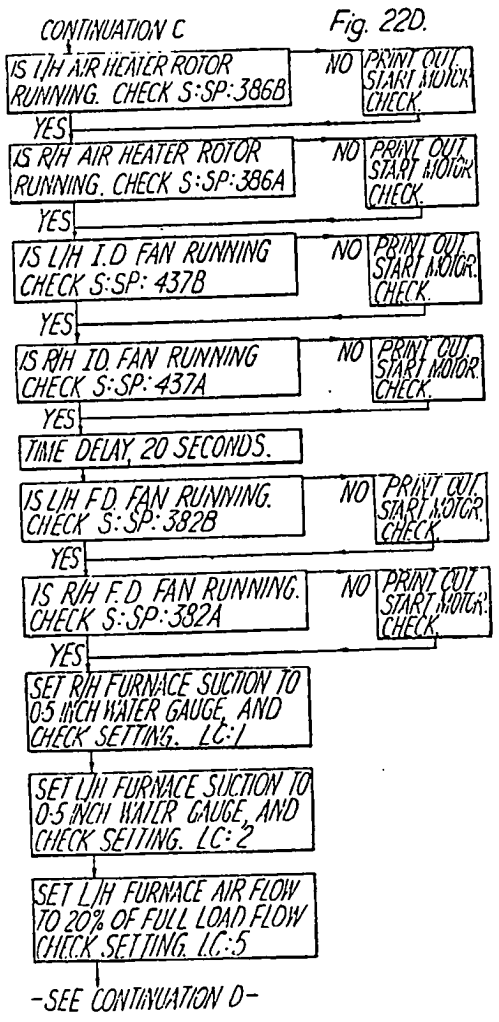
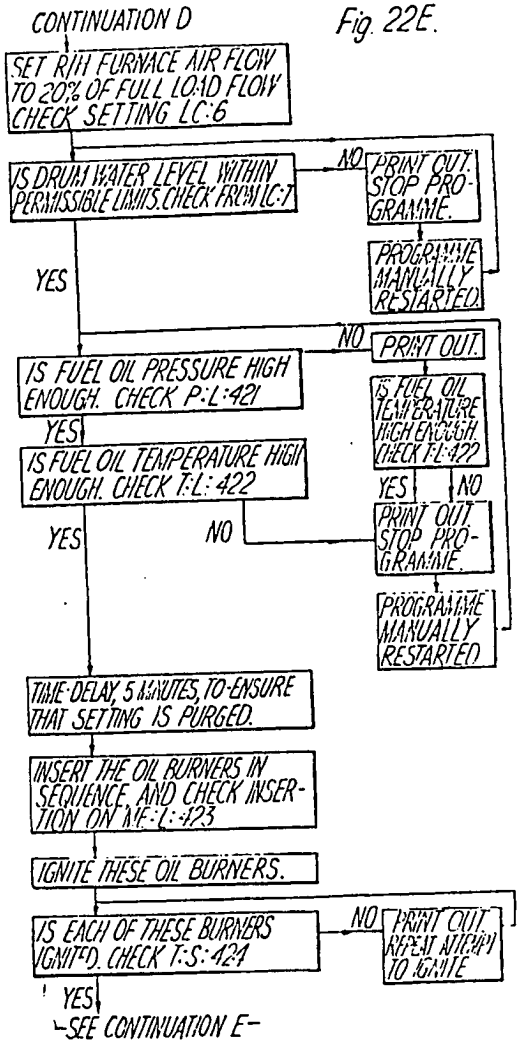



Fig. 22E.



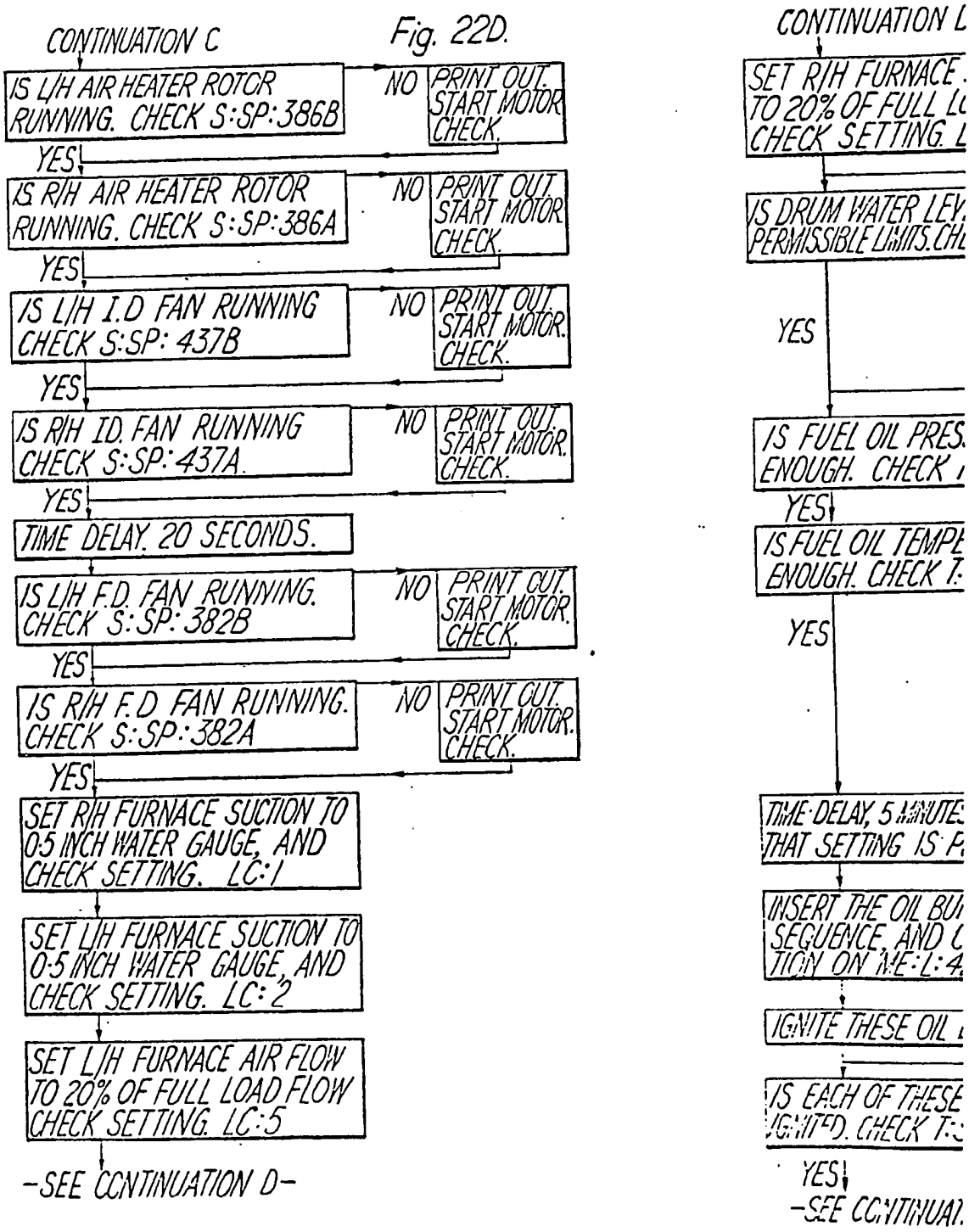
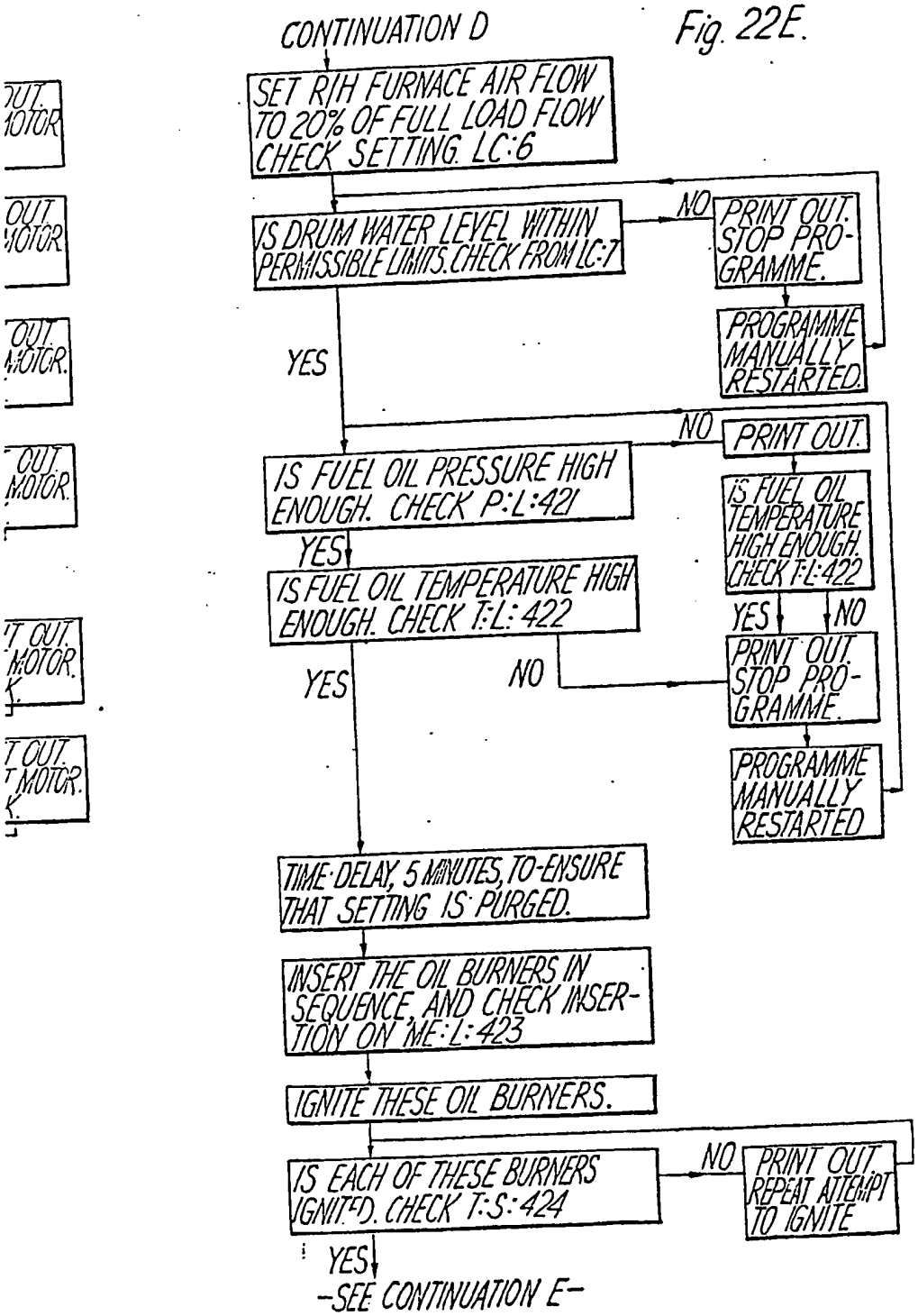



Fig. 22D.

Fig. 22E.



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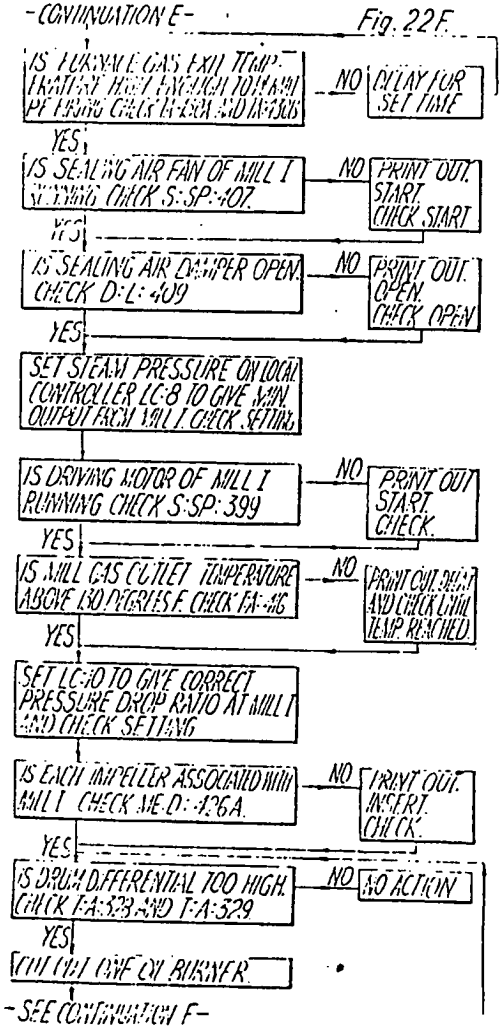
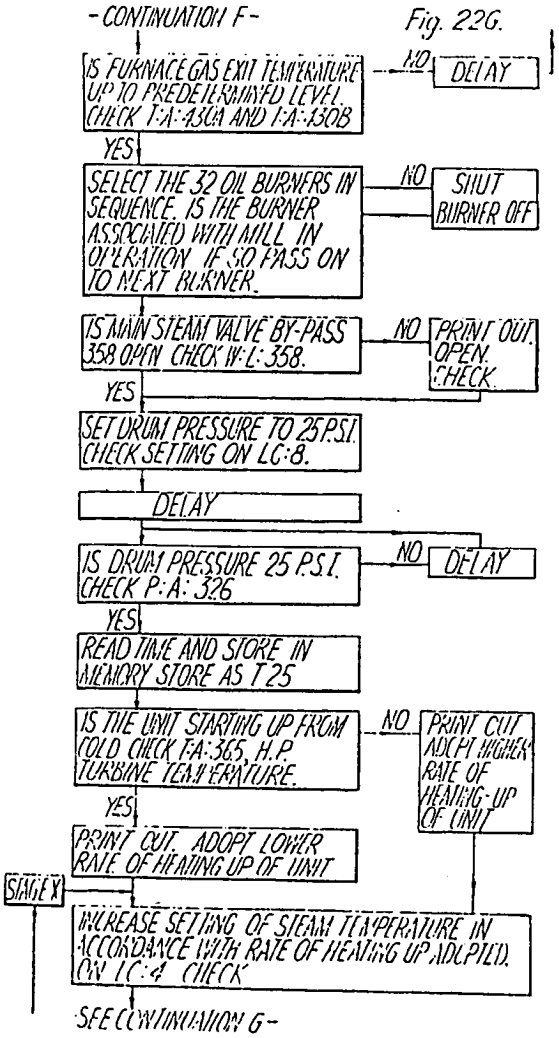
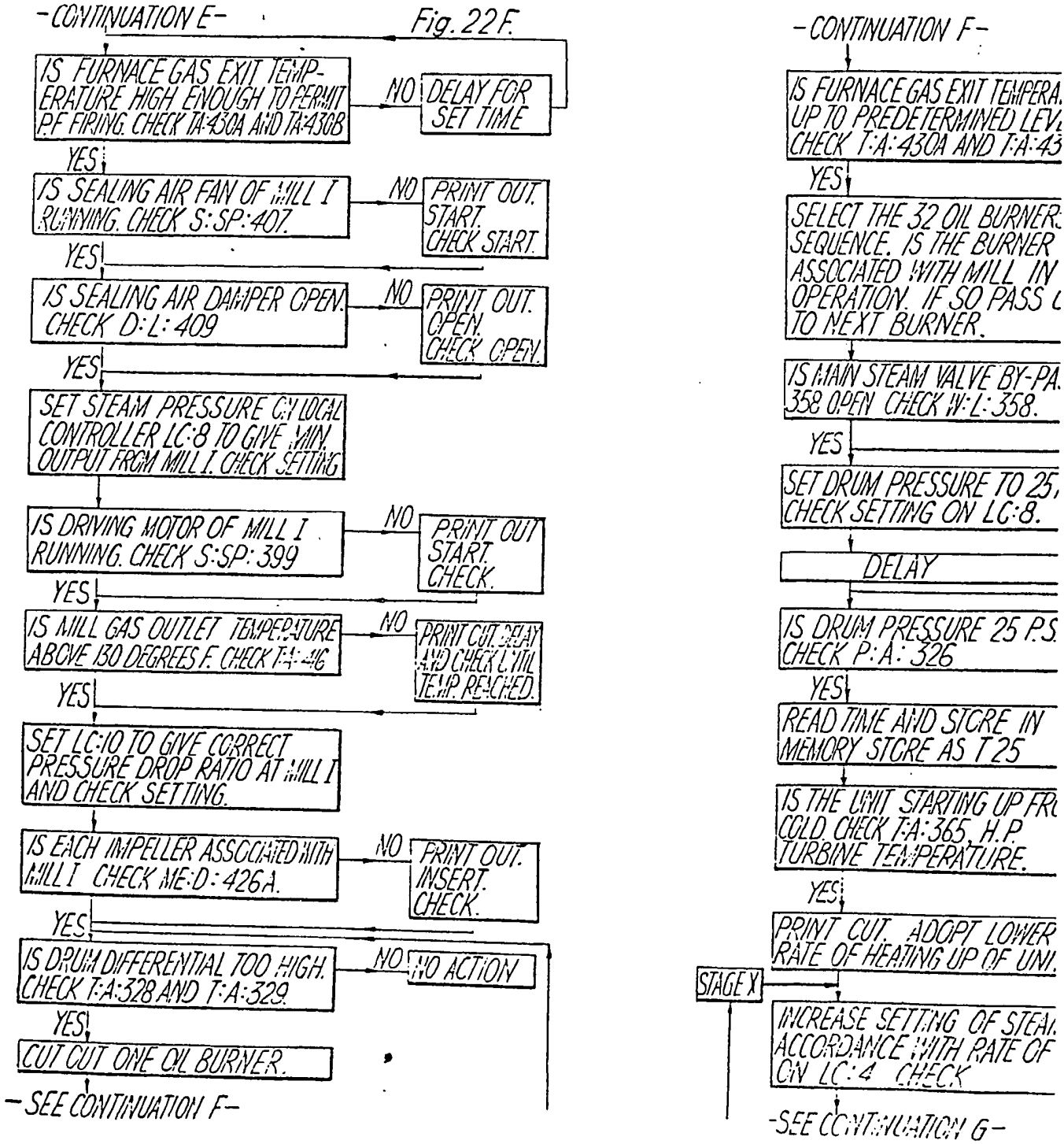
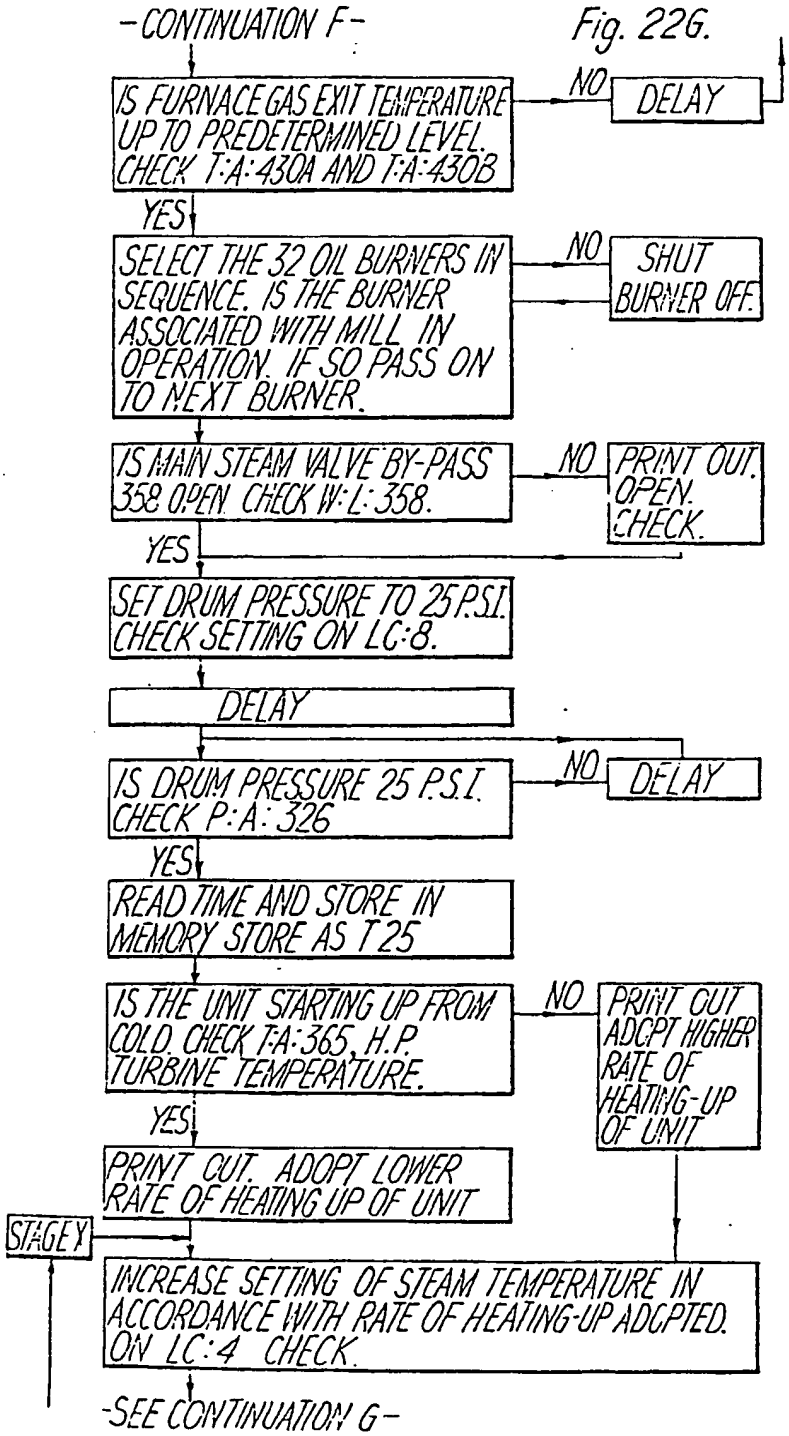






893251 COMPLETE SPECIFICATION
15 SHEETS This drawing is a reproduction of the Original on a reduced scale
Sheets 14 & 15

Fig 22H.

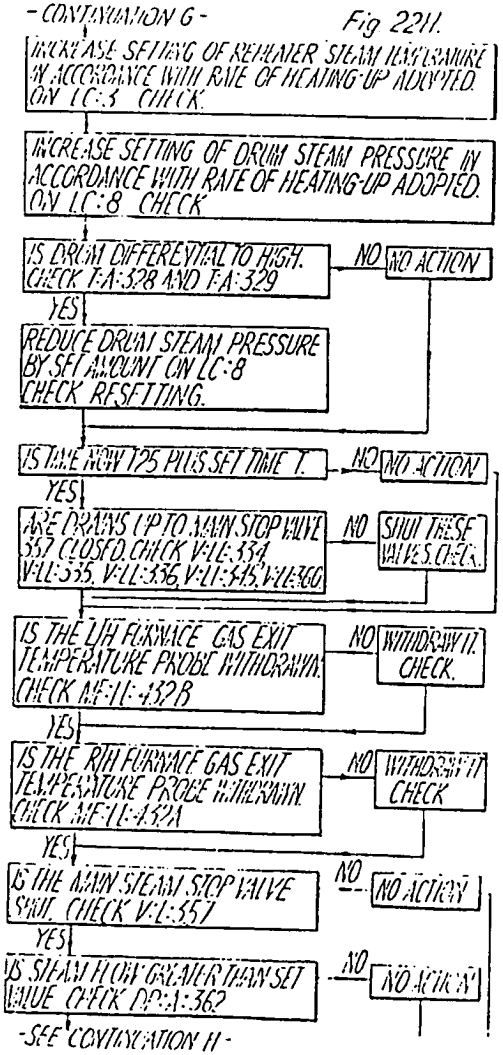
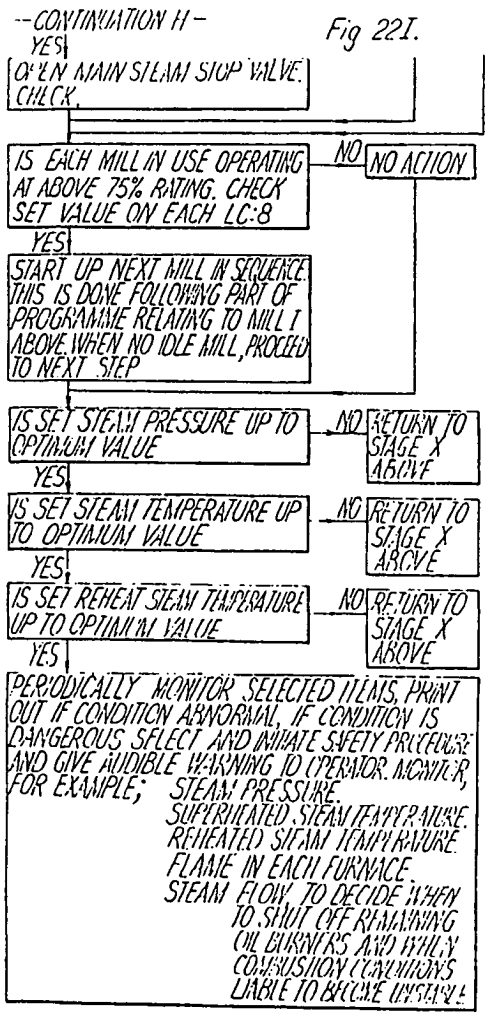



Fig 22I.



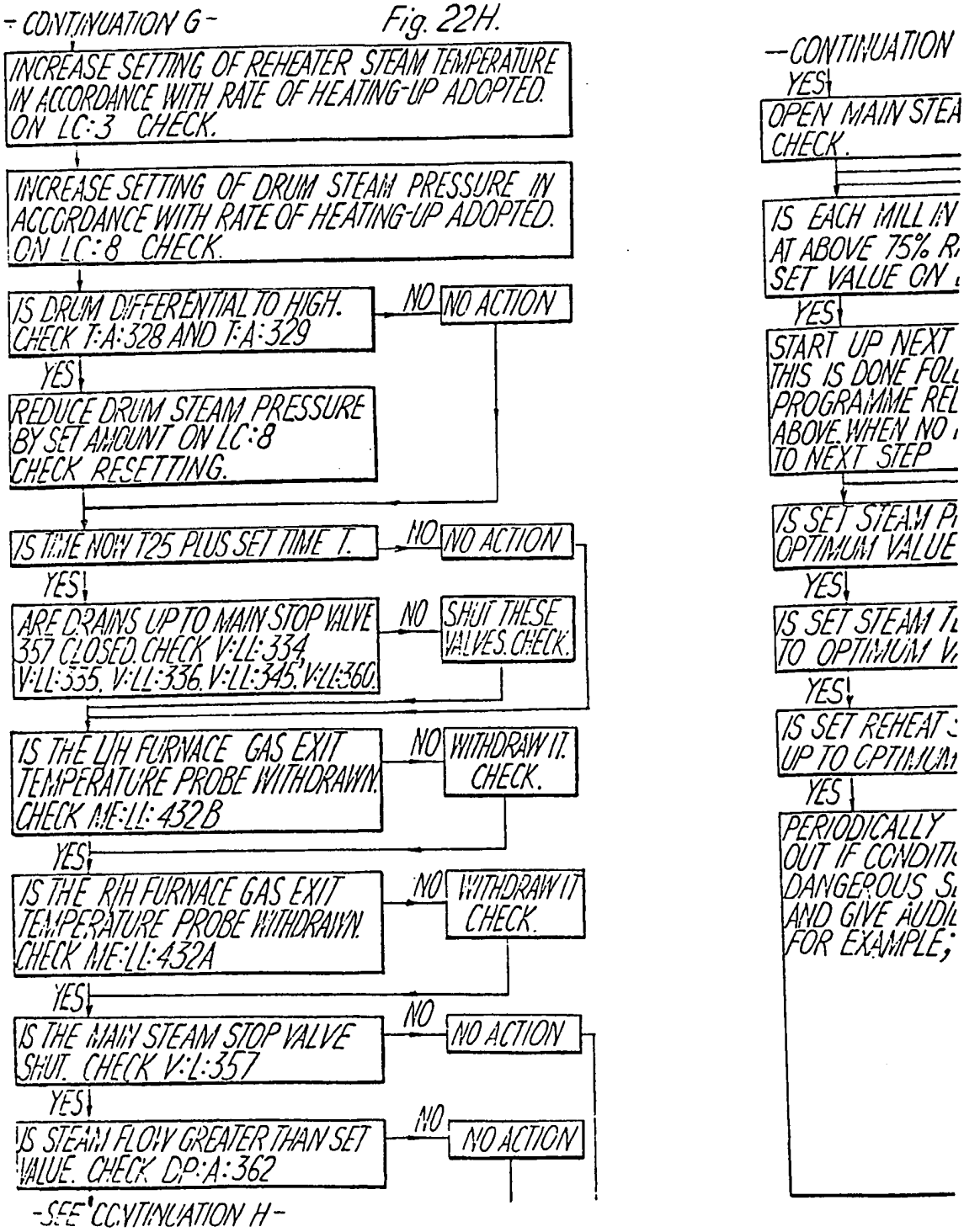



Fig. 22H.

Fig. 22I.